KPK BOARD NOTES

PHYSICS

9TH CLASS

Presented by:

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STUDY GROUP

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Unit 1

Physical Quantities and Measurement

Q.1: Define Physics. How Physics play a crucial role in science, technology and society?

Ans. Physics:

Physics is the branch of "Science" which deals with the study of

a) Matter,

b) Energy and

c) The mutual relationship of matter and energy.

Physics studies the physical universe that we live in. It helps us to understand different phenomena as

i) how to find mass of earth,

ii) what are different forms of energy and how can they be produced,

iii) motion of a car and flying of an aeroplane,

iv) what nuclear energy is and how is it produced? and many more.

Physics helps us to understand small sub-atomic particles (electrons, protons, neutrons etc) as well as large bodies (Planets, galaxies and Universe).

ROLE OF PHYSICS AS A CRUCIAL PLAYER IN SCIENCE, TECHNOLOGY AND SOCIETY:

Physics is the only branch of Science with so much diversity. It has been playing its role in almost every branch of human knowledge.

Role in Science:

Physics is used in other fields of Science like biology, chemistry, maths and computer. X-rays, Laser Therapy, Cure of Cancer and CT scan works on principles of Physics. Similarly, the structure of atoms and molecules and their bonds are explained with the help of Physics.

Role in Technology:

Physics plays an important role in the field of technology. From the mobile phones that we use to the TV screen that we use to watch cricket and news are possible just because of Physics.

Role in Society:

Physics has its main role in developing human Society. It brings us new ways to get energy, expands our study about nature, keeps us aware of the events that happen anywhere in the world and has brought us close to each other.

Q.2: Narrate a few Quranic verses which show relationship between Physics and Quran?

Ans. It is generally accepted that there are more than 700 verses in the Quran dealing with the natural phenomena. Many verses of Quran ask mankind to study nature, few are described below.

The Quran contains the following verse, regarding the origin of the universe:

"Do not the Unbelievers see That the heavens and the earth Were joined together (as one Unit of Creation), before We clove them asunder?"

[Al-Quran 21:30]

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السلام علیکم ورحمۃ اللہ وبرکاتہ:

معزز ممبران: آپ کا وٹس ایپ گروپ ایڈمن "**اردو بکس**" آپ سے مخاطب ہے۔

آپ تمام ممبران سے گزارش ہے کہ:

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- گروپ میں معزز، پڑھے لکھے، سلجھے ہوئے ممبرز موجود ہیں اخلاقیات کی پابندی کریں اور گروپ رولز کو فالو کریں بصورت دیگر معزز ممبرز کی بہتری کی خاطر ریموو کر دیا جائے گا۔
- کوئی بھی ممبر کسی بھی ممبر کو انباکس میں میسج، مس کال، کال نہیں کرے گا۔ رپورٹ پر فوری ریموو کرکے کاروائی عمل میں لائے جائے گی۔
- ہمارے کسی بھی گروپ میں سیاسی و فرقہ واریت کی بحث کی قطعاً کوئی گنجائش نہیں ہے۔
- اگر کسی کو بھی گروپ کے متعلق کسی قسم کی شکایت یا تجویز کی صورت میں ایڈمن سے رابطہ کیجئے۔
- سب سے اہم بات:

گروپ میں کسی بھی قادیانی، مرزائی، احمدی، گستاخِ رسول، گستاخِ امہات المؤمنین، گستاخِ صحابہ و خلفائے راشدین حضرت ابو بکر صدیق، حضرت عمر فاروق، حضرت عثمان غنی، حضرت علی المرتضیٰ، حضرت حسنین کریمین رضوان اللہ تعالیٰ اجمعین، گستاخ اہلبیت یا ایسے غیر مسلم جو اسلام اور پاکستان کے خلاف پراپیگنڈا میں مصروف ہیں یا ان کے روحانی وذہنی سپورٹرز کے لئے کوئی گنجائش نہیں ہے لہذا ایسے اشخاص بالکل بھی گروپ جوائن کرنے کی زحمت نہ کریں۔ معلوم ہونے پر فوراً ریموو کر دیا جائے گا۔

- تمام کتب انٹرنیٹ سے تلاش / ڈاؤنلوڈ کر کے **فری آف کاسٹ** وٹس ایپ گروپ میں شیئر کی جاتی ہیں۔ جو کتاب نہیں ملتی اس کے لئے معذرت کر لی جاتی ہے۔ جس میں محنت بھی صَرف ہوتی ہے لیکن ہمیں آپ سے صرف دعاؤں کی درخواست ہے۔
- عمران سیریز کے شوقین کیلئے علیحدہ سے عمران سیریز گروپ موجود ہے۔
- **لیڈیز کے لئے الگ گروپ کی سہولت موجود ہے جس کے لئے ویریفکیشن ضروری ہے۔**
- اردو کتب / عمران سیریز یا سٹڈی گروپ میں ایڈ ہونے کے لئے ایڈمن سے وٹس ایپ پر بذریعہ میسج رابطہ کریں اور جواب کا انتظار فرمائیں۔ برائے مہربانی اخلاقیات کا خیال رکھتے ہوئے موبائل پر کال یا ایم ایس کرنے کی کوشش ہر گز نہ کریں۔ ورنہ گروپس سے تو ریموو کیا ہی جائے گا بلاک بھی کیا جائے گا۔

نوٹ: ہمارے کسی گروپ کی کوئی فیس نہیں ہے۔ سب فی سبیل اللہ ہے

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The striking congruence between the Quranic verse and the 'Big Bang' is inescapable! How could a book, which first appeared in the deserts of Arabia 1400 years ago, contain this profound scientific truth?

Consider the following Quranic verse regarding the alternation of day and night:

"Do you not see that Allah causes the Night to enter the Day And causes the Day to enter the Night?" [Al-Quran 31:29]

Merging here means that the night slowly and gradually changes to day and vice versa. This phenomenon can only take place if the earth is spherical. If the earth was flat, there would have been a sudden change from night into day and from day into night.

"It is He Who created The Night and the Day, And the sun and the moon: All (the celestial bodies) Swim along, each in its Rounded course."

[Al-Quran 21:33]

"It is not permitted To the Sun to catch up The Moon, nor can The Night outstrip the Day: Each (just) swims along in (its own) orbit (According to Law)." [Al-Quran 36:40]

This verse mentions an essential fact discovered by modern astronomy, i.e. the existence of the individual orbits of the Sun and the Moon, and their journey through space with their own motion. The 'fixed place' towards, which the sun travels, carrying with it the solar system, has been located exactly by modern astronomy.

"He Who created the heavens and the earth and all That is between." [Al-Quran 25:59]

It would be ridiculous, for anybody to even suggest that the presence of interstellar galactic material was known 1400 years ago.

Q.3: Mention some Muslim scientists who contributed in science.

Ans. Yaqub Kindi (800 - 873):

He was born in Busra, Iraq. He produced extensive research monographs on metrology, specific gravity and tides. His most important work was done in the field of optics, especially on reflection of light.

Ibnal Haitham (965 – 1039):

He was born in Basra, Iraq. He was great scholar of his time. His greatest work is the book on optics named KITAB UL MANAZIR. He is also considered as the inventor of Pin Hole camera.

Al Beruni (973-1048):

He is afghan scholar and wrote about 150 books on physics, cosmology, geography, culture, archeology and medicine. Al Beruni discussed the shape of earth the movement of sun and moon and phases of moon.

Mohammad Abdus Salam (29 Jan 1926 - 21 Nov 1996):

He was a Pakistani theoretical physicist. A major figure in 20th century theoretical physics, he shared the 1979 Nobel Prize in Physics with Sheldon Glashow and Steven Weinberg for his contribution to the electroweak unification theory. He was the first Pakistani to receive a Nobel Prize in science.

Abdul Qadeer Khan known as A.Q. Khan (27 April 1936):

He is a Pakistani nuclear physicist and a metallurgical engineer, who founded the uranium enrichment program for Pakistan's atomic bomb project. He founded and established Kahuta Research Laboratories (KRL) in 1976, serving as both its senior scientist and Director-General until he retired in 2001.

Q.4: Write down branches of Physics in brief.

Ans. The branches of Physics are as follows.

1) Mechanics:

The branch of Physics which deals with the study of motion of objects and how are they related to forces.

2) Electricity and magnetism:

The branch of Physics which deals with the study of charges at rest and in motion.

3) Heat and thermodynamics:

The branch of Physics which deals with the study of heat, temperature and are how they related to energy.

4) Waves and oscillations:

The branch of Physics which deals with the study of waves produced on water surface, in a rope etc. and oscillations.

5) Optics:

The branch of Physics which deals with the study of light and its properties.

6) Atomic and Nuclear Physics:

The branch of Physics which deals with the study of structure and properties of individual atoms and nuclei of atoms.

7) Quantum Physics:

The branch of Physics which deals with the study of discreet indivisible units of energy called quanta.

Q.5: What are physical quantities? Distinguish between base and derived physical quantities.

Ans. Physical Quantities:

The quantities that can be measured (either directly or indirectly) are called as Physical Quantities. Physics can be called as the "the Science of Measurement", so we study only those quantities in Physics which can be measured.

Examples:

Mass of an object, Force that a bat applies on a ball, Temperature of room, Velocity of a train, Magnetic field of Earth etc.

Base Physical Quantities:

A Physical quantity in a system of measure-ment which is defined independent of other physical quantities, by means of physical standard and by procedures for comparing the quantity to be measured.

OR

Those physical quantities which are simple and easy to understand. **OR**

Those physical quantities which are proposed by a group of scientists to be considered as base physical quantities in a conference held in Paris, France in 1960.

Base physical quantities are seven in number.

Length, Mass, Time, Temperature, Amount of Current, Amount of Substance and Luminous Intensity.

Derived Physical Quantities:

The quantities that are derived from other physical quantities (the base) are known as derived physical quantities. **OR**

The physical quantities obtained from multiplication or division of Base Physical quantities.

Examples:

Force (Mass×Acceleration), Pressure (Force/Area), Density (Mass/Volume), Velocity (Length/Time), Volume (Length × Length × Length) etc.

UNITS:

- The standard with which things (quantities) are compared. **OR**

A determinate quantity (as of length, mass, time etc.) adopted as a standard of measurement.

The units of base physical quantities are called as base units and that of derived physical quantities derived units.

Q.6: What is SI? Name SI base and derived quantities and their units.

Ans. Definition:

A system of units suggested by a group of scientists in 1960 in Sevres near Paris (France), used uniformly throughout the world is known as System International De units (SI).

Base Quantities and its units:

S. No.	Physical quantity	SI unit	Unit Symbols
1	Length (L, S, D, X)	Meter	m
2	Mass (M or m)	Kilogram	Kg
3	Time (T or t)	Second	S
4	Temperature (T)	Kelvin	K
5	Luminous intensity (I)	Candela	Cd
6	Amount of Substance	mole	mol
7	Current (I)	Ampere	A

Derived Quantities and its units:

S.No.	Physical quantity	SI unit	Unit Symbols
1	Area (A)	Square Meter	m^2 (m x m)
2	Force (F)	newton	N (kg x m/s^2)
3	Speed and Velocity (V)	Meter per second	ms^{-1} (m/s)
4	Acceleration (a)	Meter per second square	ms^{-2} (m/s^2)
5	Density (ϱ)	Kilogram per cubic meter	Kgm^{-3} (kg/m3)
6	Energy and Work (E, W)	joule	J (kg x m^2/s^2)

Note: There are a lot of derived physical quantities, above are just a few.

Q.7: What is standard form or scientific notation?

Ans. Representing a very small or very large number in the form of power of ten.

Explanation:

In physics we deal with numbers that are either very small or very large, it becomes difficult to repeatedly write these numbers. For example, the mass of Earth is approximately 5,973,600,000,000,000,000,000,000 kilograms. If we use this number often, we would surely like to have a more compact notation for it.

This is exactly what standard form or scientific notation is. It represents a number as the product of a number greater than 1 and less than 10 (called the mantissa) and a power of 10 (termed as exponent):

Number (N) = mantissa (M) $\times 10^{\text{exponent (n)}}$

Mass of Earth in Scientific notation can be written as 6×10^{24} kg, whereas 6 is mantissa and 24 is exponent.

Method of Conversion:

1. In a given number N, move the decimal point and pot it after first non-zero digit which will make it mantissa (M).
2. If the decimal is moved towards left from its given initial position then the power of 10 will be positive and whatever is the number of digits through which the decimal point has been moved that will be the value of exponent (power of 10). For example 28563 will be written as 2.8×10^{4}.
3. Similarly, if the decimal point is moved towards right from its given position then the power of 10 will be negative. For example 0.0024 will be written as 2.4×10^{-3}.

Q.8: What are prefixes? Explain with examples.

Ans. PREFIXES:

Some powers of 10 have been give specific names which are called as prefixes.

These are written just before a unit and cannot be repeated for a number. It is a more convenient way to write a very large or very small number.

For example, the diameter of an atom (3.0×10^{-10} m) can be written using prefixes as 0.3 μm while that of Earth (1.27×10^{7}m) can be written as 12.7 Mm. The below table shows some of the prefixes along with its symbols.

TABLE 1.1:

Prefix	Symbol	Equivalent
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
Nano	n	10^{-9}
Micro	μ	10^{-6}
Milli	m	10^{-3}
Centi	c	10^{-2}
Deci	d	10^{-1}
Deca	da	10^{1}
Kilo	k	10^{3}
Mega or Million	M	10^{6}
Giga or Billion	G	10^{9}
Terra or Trillion	T	10^{12}
Peta	P	10^{15}
Exa	E	10^{18}

Q.9: Describe the construction and use for measurement of the following instruments:

a) Vernier calipers

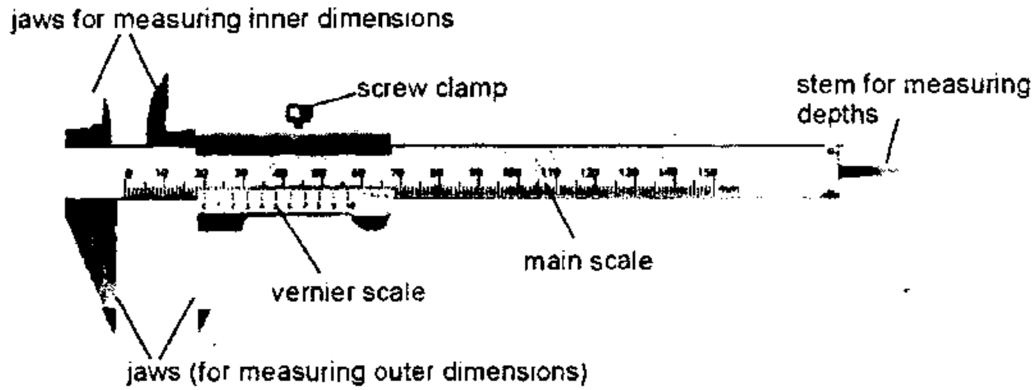
b) Screw Gauge

Ans. a) <u>Vernier callipers:</u>

Vernier calliper is a device used to measure a fraction of smallest scale division by sliding another scale

over it. It is a device used to measure small length accurately.

It can be used to measure the thickness, diameter or width of an object and the internal, external diameter of hollow cylinder.



There are two scales on Vernier callipers.

1. A main scale which has markings, usually of 1 mm each and it contains jaw A on its left end.
2. A Vernier (sliding) scale which has markings of some multiple of the marking on the main scale. The Vernier scale usually has length of 9 mm and is divided equally into 10 divisions (thus separation between two lines on Vernier scale is 9/10mm = 0.9 mm).

Least count:

Least Count = One Main Scale Division − One Vernier Scale Division

If one main scale division is 1 mm and one Vernier scale division is 0.9 mm, the least count is

Least Count = 1mm − 0.9mm = 0.1mm

We can also find the least count of a Vernier calliper by following method.

$$\text{least count} = \frac{\text{smallest division of main scale}}{\text{number of divisions of vernier scale}}$$

If the smallest main scale division is 1 mm and Vernier scale division has 10 divisions on it then the least count is

$$\text{Least Count} = \frac{1\text{mm}}{10} = 0.1 \text{ mm}$$

ZERO ERROR IN VERNIER CALLIPERS:

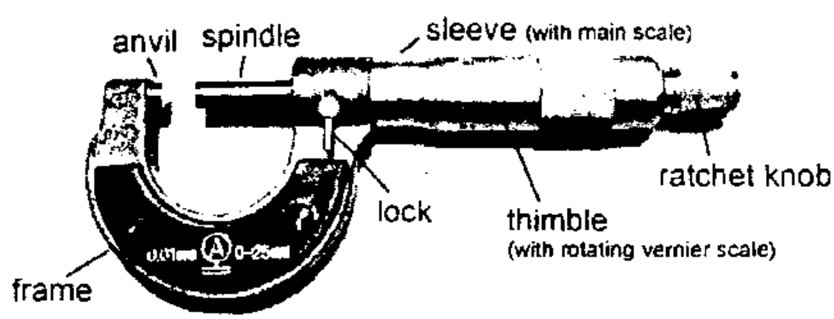
On closing the jaws of the Vernier callipers, the zero of the Vernier Scale may or may not coincide with the zero of the main Scale. If their zeros do not coincide, there is zero error in the instrument.

b) Screw Gauge:

A device used to measure the dimensions (length, diameter and volume etc) of very small objects to the level of 0.01 mm, by rotating circular scale over main scale.

Pitch of a screw gauge:

The distance travelled by the circular scale on linear scale in one rotation is called the pitch of the screw.



Least Count and pitch of Screw Gauge:

The minimum length which can be measured accurately by a screw gauge is called least count of the screw gauge. The least count of screw gauge is found by dividing its pitch by the number of circular scale divisions.

Then, pitch of the screw =

$$\frac{\text{Distance moved by screw}}{\text{No. of full rotations given}} = \frac{5}{5} = 1\text{mm}$$

Now, count the total number of divisions on circular (head) scale.

Then, least count

$$= \frac{\text{Pitch}}{\text{Total number of divisions on the circular scale}}$$

$$= \frac{1}{100} = 0.01\text{mm}$$

The least count is generally 0.001 cm

Q.10: What is meant by the significant figures of measurement? What are the main points to be kept in mind while determining the significant figures of a measurement?

Ans. **Significant figures:**

The number of accurately known figures and the first doubtful figure in a reading are known as significant figures.

Explanation:

There are two types of values, exact and measured. Exact values are those that are counted clearly. For example, counting number of chairs in a classroom or number of teachers in a school.

On the other hand, values associated with measurements of any kind are uncertain to some extent. If we find the length of a rod using a meter ruler have least count of 1mm. The resultant value is between

50mm and 51mm. Here we can estimate the value to be 50.5mm. This value (50.5mm) is accurate in mm up to 50, the last digit 5 is doubtful figure.

GENERAL RULES FOR WRITING SIGNIFICANT FIGURES

1. All NON-ZERO digits are significant. That is all the digits from 1 to 9 are significant. For example, the number of significant figures in 567.56 is 5.
2. ZERO in between two significant digits is always significant. For example, the number of significant figures in 75.7007 is 6.
3. ZEROs to the left of significant figures are not significant. For example, the number of significant figures in 0.023567 is 5.
4. ZEROs to the right of the significant figure may or may not be significant. In decimal fractions zero to the right of a decimal fraction are significant. For example, in 54.20 there are 4 significant figures. However, if the number is an integer, number of significant figures can be found out by accuracy of the measuring instrument. For example, in number 3000 we may have 1, 2 or even 4 significant figures.
5. In scientific notation or standard form the figures other than power of ten are all significant. For example, mass of earth is 5.98×10^{24} kg, there are 3 significant figures in this value 5, 9 and 8.

A single rule, how to find number of significant figures in a reading:

Start counting number of significant figures from extreme left non-zero digit and stop counting on the extreme right digit, either zero or non-zero.

RULES FOR ROUNDING OFF SIGNIFICANT FIGURES

1. If the last digit is less than 5 then it will be ignored. e.g. 3.84 are rounded to 3.8.
2. When the dropping digit is greater than 5 then the last retained digit increases by 1 e.g. 86.69 is rounded to 86.7.
3. When the dropping digit is 5 and the last retained digit is even then the last digit i.e. 5 will be dropped without affecting the next one. e.g. 3.65 are rounded to 3.6.
4. If the last digit is 5 and the 2nd last is an odd digit then the 2nd last digit is increased by 1 in order to round off 5, e.g. 6.75 is rounded to 6.8.

EXAMPLES AND ASSIGNMENTS

Example 1.1:

Average distance between earth and moon is 384,400,000m, write this number in Standard form / scientific notation.

Solution:

For Standard form / scientific notation we can write the term as

Distance=384400000.0×10^0m

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is nonzero, we have to move the decimal 8 digits towards left. Therefore, the power of 10 will be positive 8, that is

$$\boxed{\text{Distance} = 3.844\times10^{8}\text{m}}$$

Which is the average distance between earth and moon in standard form / scientific notation.

Extension Exercise 1.1 Hint:

Earth revolves around the sun in an elliptical (Not Circular) path that is why the distance between Earth and Sun Changes a little. So, we take its average value.

Assignment# 1.1:

The mass of Earth is 5,980,000,000,000,000,000,000,000kg, write this number in Standard form / scientific notation.

Solution:

Mass = 5,980,000,000,000,000,000,000,000.0 kg

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is nonzero, we have to move the decimal 24 digits towards left. Therefore, the power of 10 will be positive 24 that is Mass = $\boxed{5.98\times10^{24}\text{kg}}$

EXAMPLE 1.2

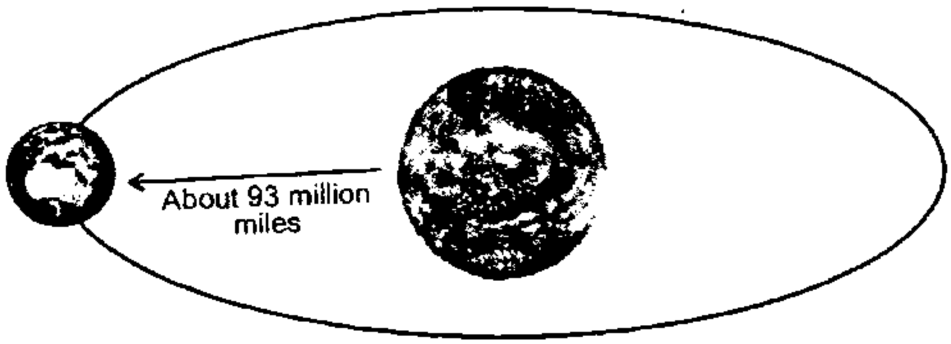
NUMBER OF SECONDS IN A YEAR:

Find the number of seconds in a year and write the answer in Standard form / scientific notation.

Solution:

We know that there are 365 days in a year, 24 hr in a day, 60 minutes in an hour, and 60s in a minute. These four relationships are conversion factors.

The earth's revolution around the sun



The Earth's travels in an orbit around the Sun. When drawn, the orbit path looks like an ellipse and this is one revolution around the Sun. It takes **365 days and about 6 hours** for the Earth to make one complete revolution around the Sun. This means that the Earth is moving around the Sun at a speed of about 66,600 miles per hour!

Starting with 1 yr and multiplying by these conversion factors, we obtain

$$1y = 1\cancel{y} \times \frac{365\cancel{d}}{1\cancel{y}} \times \frac{24\cancel{h}}{1\cancel{d}} \times \frac{60\cancel{m}}{1\cancel{h}} \times \frac{60s}{1\cancel{m}}$$

Or $1y = 1 \times 365 \times 24 \times 60 \times 60s$

Or $\boxed{1y = 31536000\ s}$

For Standard form / scientific notation we can write the term as $1y = 31536000.0 \times 10^0$ s

For Standard form in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 7 digits towards left. Therefore, the power of 10 will be positive 7, that is

$$\boxed{1y = 3.1536 \times 10^7 s}$$

Extension Exercise 1.2:

No, this value is not exact. As After each 4 year we have a leap year in which we have 366 days, so we take average value of days in a year to be 365.25 and the number of seconds will then be 31,557,600.

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ASSIGNMENT 1.2: SECONDS IN A WEEK

Calculate the number of seconds in a week. Express the number in power of 10 notations.

Solution:

We know that there are 7 days in a week. 24 hr in a day, 60 minutes in an hour, and 60 s in a minute. These three relations are conversion factors.

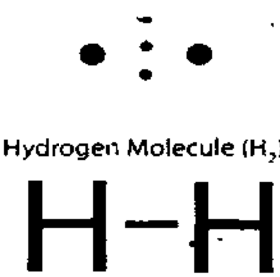
$$1w = 1\cancel{w} \times \frac{7\cancel{d}}{1\cancel{w}} \times \frac{24\cancel{h}}{1\cancel{d}} \times \frac{60\cancel{m}}{1\cancel{h}} \times \frac{60s}{1\cancel{m}}$$

$$1w = 1 \times 7 \times 24 \times 60 \times 60s = \boxed{604{,}800s}$$

For Standard form / scientific notation we can write the term as

$$1\ w = 604{,}800.0 \times 10^0 s$$

For Standard form in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 5 digits towards left. Therefore, the power of 10 will be positive 5, that is


Hydrogen Molecule (H_2)

$$\boxed{1\ w = 6.048 \times 10^5 s}$$

EXAMPLE 1.3 SMALLEST MOLECULE:

The smallest molecule is the diatomic hydrogen (H_2) with a bond length of 0.000,000,000,074m. Write the answer in Standard form / scientific notation.

Solution:

In Standard form/scientific notation we can write the term as

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Bond length= $0.000000000074 \times 10^0$m

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 11 digits towards right. Therefore, the power of 10 will be negative 11, that is

$$\boxed{\text{Bond length} = 7.4 \times 10^{-11}\ \text{m}}$$

ASSIGNMENT 1.3: AVERAGE MASS OF HOUSEFLY:

Adult housefly (Musca domestica) is having a mass of only about 0.000,021,4kg. Express this number in standard form / scientific notation.

Solution:

In Standard form / scientific notation we can write the term as

Mass of housefly = $0.000{,}021{,}4 \times 10^0$ kg

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 5 digits towards right. Therefore, the power of 10 will be negative 5, that is

$$\boxed{\text{Mass of housefly} = 2.14 \times 10^{-5}\ \text{kg}}$$

EXAMPLE 1.4 SIZE OF BACTERIUM

A typical bacterium has a mass of 2.0 fg. Express this measurement in terms of kg.

Solution:

Tuberculosis is a respiratory disease (infectious) caused by a bacterium known as **Mycobacterium tuberculosis.**

We know that 1 fg = 10^{-15} g and 1 kg = 10^3 g

mass of bacterium = 2.0 fg

$$\text{mass of bacterium} = 2.0 \times 10^{-15} \times \cancel{g} \times \frac{1\text{kg}}{1\times 10^{3}\cancel{g}}$$

$$\boxed{\text{mass of bacterium} = 2.0 \times 10^{-18}\ \text{kg}}$$

ASSIGNMENT 1.4: SMALLEST BIRD:

The smallest bird is the bee hummingbird. Males measure only 0.057 m. Convert this number to standard form and write this number in millimetre.

Solution:

In Standard form / scientific notation we can write the term as

Given Measurement = 0.057 m

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 2 digits

towards right. Therefore, the power of 10 will be negative 2, that is

Measure = 5.7×10^{-2} m

It can be written as 57×10^{-3} m = $\boxed{57\text{mm}}$

EXAMPLE 1.5 PESHAWAR TO LAHORE VIA MOTORWAY:

The distance from Peshawar to Lahore through motorway is 489 km, convert this number to megametre (Mm).

Solution:

We know that

1 km = 1×10^3 m

1 Mm = 1×10^6 m

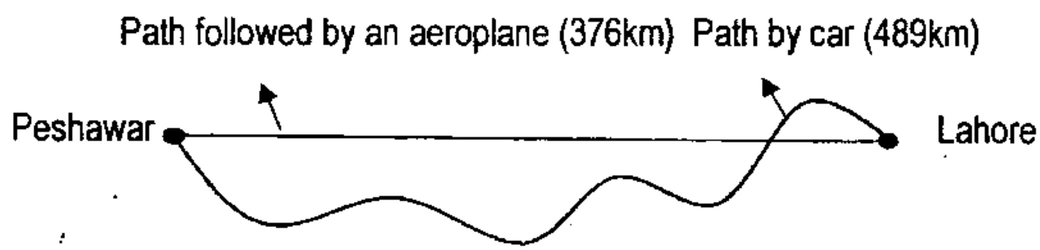
$$489\text{ km} = 489 \times 10^3 \cancel{m} \times \frac{1\text{Mm}}{1 \times 10^6 \cancel{m}}$$

489 km = 489×10^{-3} Mm

489 km = $\boxed{0.489\text{ Mm}}$

EXTENSION EXERCISE 1.3 Hint:

The distance shortens because of the straight path followed by aeroplane while a car will use only road which is a zigzag path as shown below.



ASSIGNMENT 1.5: mm TO LAHORE:

Calculate the distance from Peshawar to Lahore in millimetres.

Solution:

Given distance = 489 km

As 1 km = 1000 m

and 1 m = 1000 mm

So, 1 km = 1,000,000 mm

Now

Given distance = 489 km

$= 489 \times 1{,}000{,}000$ mm

$= 489{,}000{,}000$ mm

$= \boxed{4.89 \times 10^8 \text{ mm}}$

ASSIGNMENT 1.6: WHICH INSTRUMENT IS MORE ACCURATE?

Which of the following is the accurate device for measuring length?

A). A Vernier calliper with main scale of 1 mm marking and 50 divisions on the sliding scale

B). A screw gauge of pitch 1 mm and 25 divisions on the circular scale.

Ans. Vernier Calliper here will give more accurate result than Screw Gauge.

An accurate device is that for which least count is smaller.

Least count of given Vernier Calliper (using above formula) is 0.02 mm and that of given Screw gauge will be (using above formula) 0.04 mm.

EXAMPLE 1.6 ONE LITRE MILK VOLUMES IN SI UNITS:

A litter (L) is the volume of a cube that is 10 cm by 10 cm by 10 cm. If you drink 1 L of milk, how much volume (a) in cubic centimetres and (b) in cubic meters would it occupy in your stomach?

Solution:

(a) The volume of a cube of side L is $V=L^3$. The volume in cm^3 is found directly from L =10 cm. Calculate the volume in cm is

$V = L^3 = (10\ cm)^3 = 10^3\ cm^3$

(b) To find the volume in m, convert cm to m using the conversion factor $1\ cm = 10^{-2}\ m$.

$10^3\ cm^3 = 10^3\ cm^3 \times (10^{-2}\ m/1\ cm)^3$

$10^3\ cm^3 = 10^3\ \cancel{cm^3} \times 10^{-6} m^3/ 1\ \cancel{cm^3}$

$10^3\ cm^3 = \boxed{10^{-3}\ m^3}$

ASSIGNMENT 1.7: mL CONVERSION:

A beaker contains 200 mL of water, what is volume of water in cm^3 and m^3.

Solution:

As we know that

$1m^3 = 10^6$ milliliters (10^6 mL)

So, $1\ mL = 10^{-6}\ m^3$

Then $200\ mL = 200 \times 10^{-6}\ m^3 = 2.0 \times 10^{-4}\ m^3$

Now $2.0 \times 10^{-4}\ m^3 = 2.0 \times 10^{-4}\ (100\ cm)^3$

$= 2.0 \times 10^{-4} \times 10^{6}\ cm^3$

$= \boxed{2.0 \times 10^{2}\ cm^3}$

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. How many millimetres are there in 10 cm?

   A. 100 mm B. 200 mm
   C. 50 mm D. 10 mm

2. Which of the following can be measured using a micrometre?

   A. current B. Force
   C. Length D. mass

3. The instrument best measures the internal diameter of a pipe is

   A. screw gauge B. Vernier caliper
   C. meter rule D. measuring tape

4. Which prefix represents a largest value?

   A. mega B. giga
   C. peta D. exa

5. Which of the following is the smallest unit?

   A. atto B. pico
   C. nano D. femto

6. Which of the following numbers shows one significant digit?

   A. 1.1 B. 6.0

   C. 7.1 D. 6×10^2

7. Which of the following numbers shows 4 significant digits?

   A. 900.8 B. 4

   C. 5174.00 D. 0.0002

8. A light year is distance travelled by light in one year. It travels about 9.460×10^{15} m. How many significant figures are in this number?

   A. 6 B. 2

   C. 3 D. 4

9. 0.2 mm in units of meters is

   A. 0.0002 m B. 2×10^{-4} m

   C. both A and B D. none

10. KITAB UL MANAZIR is the name of book written by

   A. Yaqoob Kindi B. Ibnal Haitham

   C. Al Beruni D. none

ANSWERS:

1.A	2.C	3.B	4.D	5.A	6.D	7.A	8.D	9.C	10.B

CONCEPTUAL QUESTIONS

Q.1: How technology is shaped by physics?

Ans. It became possible because of physics that large vacuum tubes are replaced by integrated circuits (ICs). It reduced the size of Screens.

Communication is improved because of physics e.g. mobiles and computers.

Engines made it possible for better and quick travel and industries.

Electrical appliances are possible because of physics e.g. AC, Refrigerator, Fan etc.

Q.2: Physics and biology are considered different branches of science, how Physics links with Biology?

Ans. For the study of microorganisms we use Microscope which is a technology given by Physics that works on the principles of optics.

A lot of instruments used for medical purposes are a gift of Physics. Like X-Ray, Ultrasound, Blood pressure machine, ECG, EEG and MRI etc.

Apart from this, Physics is also used for curing different diseases like for curing cancer Radiation Physics is used.

Q.3: Why are measurements important?

Ans. Measurements are much important in dealing with things. Suppose you say that this table is large. No one can get an idea of its size until you use a number with a proper unit (5 m), which is called measurement, to represent its size. In the same sense if you say that this object is heavy, no one can get idea of its mass until you give it a numerical value.

Q.4: Why area is a derived quantity?

Ans. Area is a derived quantity as it comes from the multiplication of two length elements as

$$A = L \times L$$

Since unit of length is meter (m), Unit of Area will become

$$A = m \times m = m^2$$

Hence Area is a derived quantity and so its unit is a derived unit which comes from the multiplication of a base quantity (m) with itself.

Q.5: Name any four derived units and write them as their base units?

Ans.

S.No.	Derived Unit	Representation in base units
1	newton (N) {Force}	$N = kg\ m\ s^{-2}$
2	joule (J) {Work or E}	$J = N\ m = kg\ m^2\ s^{-2}$
3	Cubic meter (m^3) {Volume}	$m^3 = m \times m \times m$
4	newton per square meter (N/m^2) {Pressure}	$N\ m^{-2} = kg\ m^{-1}\ s^{-2}$

Q.6: Why in physics we need to write in scientific notation?

Ans. In measurements, sometimes we deal with very small or very large numbers which are very difficult to repeatedly write in problems. For this purpose, we write it in scientific/standard notation.

For example, thickness of a paper is 0.0005m. In a problem if we are dealing with it then it is difficult to write it again and again. So, we write it in scientific notation as 5×10^{-4}m which is more comfortable.

Q.7: What is least count? How least count for Vernier calliper and screw gauge are defined?

Ans. The smallest value that an instrument can measure is called as its least count.

Least count of Vernier callipers:

Least Count = One Main Scale Division – One Vernier Scale Division

If one main scale division is 1 mm and one Vernier scale division is 0.9 mm, the least count is

$$\text{Least Count} = 1\text{mm} - 0.9\text{mm} = 0.1\text{mm}$$

We can also find the least count of a Vernier calliper by following method.

$$\text{Least Count} = \frac{\text{smallest division of main scale}}{\text{number of division of vernier scale}}$$

If the smallest main scale division is 1 mm and Vernier scale division has 10 divisions on it then the least count is

$$\text{Least Count} = \frac{1\text{mm}}{10} = 0.1\text{ mm}$$

Least count of Screw gauge:

Then, pitch of the screw =

$$\frac{\text{Distance moved by screw}}{\text{No. of full rotations given}} = \frac{5}{5} = 1\text{mm}$$

Now, count the total number of divisions on circular (head) scale.

Then, least count

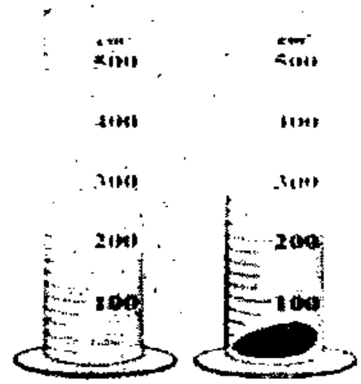
$$= \frac{\text{Pitch}}{\text{Total number of divisions on the circular scale}}$$

$$=\frac{1}{100}=0.01\text{mm}$$

The least count is generally 0.001 cm

Q.8: How can we find the volume of a small pebble with the help of measuring cylinder?

Ans. Water is poured into a measuring cylinder until the cylinder is about half full. The volume is measured, and then a small pebble is lowered in the measuring cylinder. This will increase the volume of water a little. Read the reading of cylinder once again. Subtract the first value of volume (without pebble) from that of second value (with pebble) as



Volume of pebble = Volume of water (with pebble) Volume of Water (without pebble)

NUMERICAL PROBLEMS

Q.1: Write the number in prefix to power of ten in following examples.

(a) Mechanical nano-oscillators can detect a mass change as small as 10^{-21} kg.

(b) The nearest neutron star (a collapsed star made primarily of neutrons) is about 3.0×10^{18} m away from Earth.

(c) Earth to sun distance is 149.6 million km

Solution:

(a). Mass = 10^{-21} kg = $10^{-21} \times 10^{3}$ g = 10^{-21+3} g

= 10^{-18} g = 1 atto gram = 1 ag.

(b). Distance = 3.0×10^{18} m = 3.0 exa meter

= 3.0 em.

(c). Distance = 149.6 million km

= $149.6 \times 10^{6} \times 10^{3}$ m

= 149.6×10^{9} m= $\boxed{149.6\ \text{Gm}}$

Q.2: An angstrom (symbol Å) is a unit of length (commonly used in atomic physics), defined as 10^{-10} m which is of the order of the diameter of an atom.

(a) How many nanometres are in 1.0 angstrom?

(b) How many femtometres or fermis (the common unit of length in nuclear physics) are in 1.0 angstrom?

(c) How many angstroms are in 1.0 m?

Solution:

(a). 1.0 angstrom = 10^{-10} m = $10^{-1} \times 10^{-9}$ m

= 10^{-1} nanometres = 10^{-1} nm = $\boxed{0.1\ \text{nm}}$

So, there are 0.1 nanometres in 1.0 angstrom.

(b). 1.0 angstrom = 10^{-10} m = $10^{5} \times 10^{-15}$ m

= 10^{5} femtometres = 10^{5} fm = $\boxed{100{,}000\ \text{fm}}$.

So, there are 100,000 femtometres in 1.0 angstrom.

(c). 1.0 angstrom = 10^{-10} m or

$$1\text{ m} = 1/10^{-10}\,\text{Å} = \boxed{10^{10}\,\text{Å}}$$

So, there are 10^{10} Å in 1.0 m.

Q.3: The speed of light is c = 299,792,458 m/s.

(a) Write this value in scientific notation.

(b) Express the speed of light to (i) five significant figures, (ii) three significant figures.

Solution:

(a). speed of light = 299,792,458m/s

$$= 299{,}792{,}458.0 \times 10^{0}\text{ m/s}$$

We will shift the decimal to a position where only one digit is to the left of decimal i.e. to in between 2 and 9. That is

Speed of light = $\boxed{2.99792458 \times 10^{8}\text{ m/s}}$

(b). rounding off:

(i). Speed of light = 2.99792458×10^{8} m/s

We will only leave 5 digits in the final result.

65 No change No change

$= 2.99792458 \times 10^{8}$ m/s. $= 2.9979246 \times 10^{8}$ m/s

$= 2.997925 \times 10^{8}$ m/s $= 2.99792 \times 10^{8}$ m/s

So, final result is $\boxed{2.9979 \times 10^{8}\text{ m/s}}$

(ii). Speed of light = 2.9979×10^{8} m/s

$$= 2.998 \times 10^{8}\text{ m/s} = \boxed{3.00 \times 10^{8}\text{ m/s}}$$

Q.4: Express the following in terms of powers of 10.

(a) 7 nanometre **(b) 96 megawatt**

(c) 2 gigabyte **(d) 43 picofarad**

(e) 2 millimetres.

Solution:

(a). As 1 nanometre = 10^{-9} metres.

So, 7 nanometres = $\boxed{7 \times 10^{-9} \text{ metres}}$

(b). As 1 Megawatt = 10^{6} watts.

So, 96 megawatts = 96×10^{6} watts

= $\boxed{9.6 \times 10^{7} \text{ watts}}$

(c). As 1 Gigabyte = 10^{9} bytes.

So, 2 Gigabytes = $\boxed{2 \times 10^{9} \text{ bytes}}$

(d). As 1 picofarad = 10^{-12} farads.

So, 43 picofarad = 43×10^{-12} farads

= $\boxed{4.3 \times 10^{-11} \text{bytes}}$

(e). As 1 millimetre = 10^{-3} metres.

So, 2 millimetres = $\boxed{2 \times 10^{-3} \text{ metres}}$

Q.5: Write the following numbers in standard form:

(a) Mass of Bacterial cell: 0.000,000,000,005 kg

(b) Diameter of Sun: 1,390,000,000 m

Solution:

(a). Mass of Bacterial cell = 0.000,000,000,005 kg

= $0.000,000,000,005 \times 10^{0}$ kg

To write it in standard form we have to shift decimal to a position where there is only one non-zero digit to the left of the decimal. Here we have to shift decimal to the right of 5 i.e. a total of 12 steps towards right. Therefore, the power of 10 will be negative 12, that is

Mass of Bacterial cell = $\boxed{5 \times 10^{-12}\ \text{kg}}$

(b). Diameter of Sun = 1,390,000,000m

$= 1{,}390{,}000{,}000.0 \times 10^{0}$ m

To write it in standard form we have to shift decimal to a position where there is only one non-zero digit to the left of the decimal. Here we have to shift decimal to, in between 1 and 3 i.e. a total of 9 steps towards left. Therefore, the power of 10 will be positive 9. That is

Diameter of Sun = $1.390{,}000{,}000 \times 10^{9}$ m

$= \boxed{1.39 \times 10^{9}\ \text{m}}$

--❀❀❀--

Unit 2

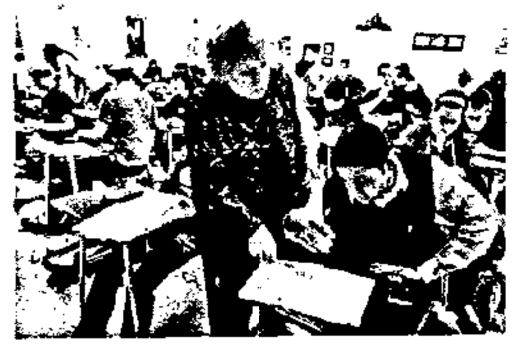
Kinematics

Q.1: What is motion? Describe that motion is relative. How two observers in relative motion can have conflicting views about same object?

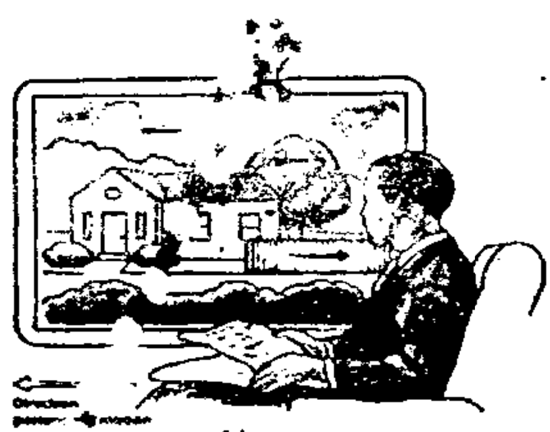
Ans. Motion:

When a body changes its position relative to its surrounding then we say that the body is in motion.

Explanation:



Motion is a relative quantity. You can only say that object is in motion with respect to some other objects. There is no absolute motion. For example, when teacher changes her position in the classroom while students are sitting on their chairs. According to students' observation the teacher is in motion. Interestingly, teacher while moving also observes the students to move as well as shown in figure below.



Consider another example that a person is setting in a bus and the bus just passes a home. The man setting in the bus observes that the bus is at rest and it is the home that is moving backward. While for a person setting in this home, he is at rest and it is the bus which is in motion. Both the persons have conflicting views that is why we say that rest and motion are relative quantities and not absolute.

Q.2: Explain different types of motion and give an example of each.

Ans. When a body changes its position relative to its surrounding we say that it is in motion. Following are different types of motions along with examples.

(a) **Translatory motion:**

The motion of a body in a straight line, a curved path or in an irregular way is called as Translatory motion. For example, a ball hit by a batsman, a car moving on road, a bird flies etc. This type of motion is further divided into three categories.

(i) *Motion of a body in a straight line is called as rectilinear motion.* For example, motion of an apple that falls from a tree.

(ii) *Motion of a body in a circular or curved path is called as curvilinear*

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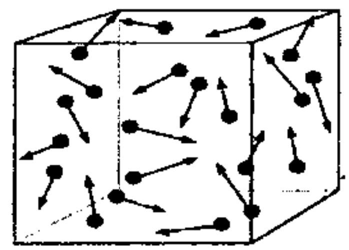
motion. For example, motion of a football kicked by the footballer.

(iii) *Motion of a body in an irregular way is called as Random motion.* For example, motion of air particles, flying of a bird.

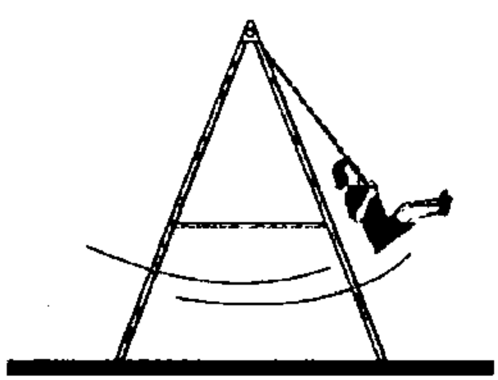


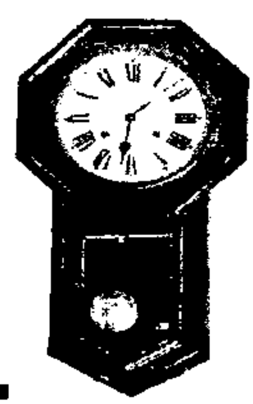
(b) Rotatory motion:

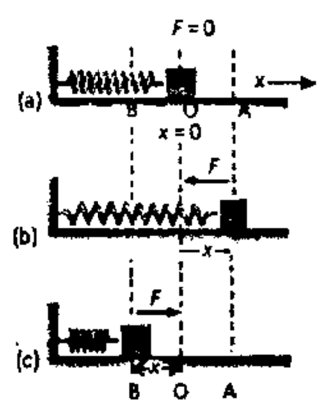
The motion of a body, as a whole, around a fixed point is called as rotatory motion. For example, motion of wheels of a car, the wings of a helicopter etc.

(c) Vibratory motion:

The motion of a body, as a whole, repeatedly forward and backward about its mean position is called as vibratory motion. For example, motion of a swing, motion of a pendulum clock and mass attached to the spring as shown below.







Note:

This doesn't mean that the motion will only be translatory, rotatory or vibratory at a time. A body can have any two or three types of motion at the same time. For example, motion of a wheel of a car travels translatory as well as rotatory motion at the same time.

Q.3: Define scalar and vector quantities. Explain with example the graphical representation of vector quantities.

Ans. Physical quantities are divided into the following two broader categories in terms of direction.

❖ **Scalar quantities:**

Those physical quantities which are completely described by its magnitude (numerical value with a proper unit) only and do not require direction are called as Scalar quantities. For example, if someone tells you to bring 5 kg of sugar from store you clearly understand it. Similarly, time is also a scalar quantity.

Scalar quantities can be added, subtracted, multiplied or divided by simple algebra. For example, 5 seconds and 10 seconds will just simply add up to give a total of 15 seconds.

Examples:

Distance, Time, Mass, Temperature, Area, Volume, Density, Speed, Energy etc.

❖ **Vector Quantities:**

Those physical quantities which cannot be completely described by its magnitude only but also require direction, are called as Vector quantities. For example, if

someone tells you that I applied a force of 10 Newton on a body you will be confused about its direction. So, force is a vector quantity.

Vector quantities cannot be added or multiplied by simple algebra but need a special procedure which will be discussed later.

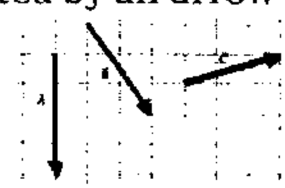
Vectors are represented by bold capital letters (**A, B, F**) or by capital letters having arrow above ($\vec{A}, \vec{B}, \vec{F}$) or below ($\underset{\rightarrow}{A}, \underset{\rightarrow}{B}, \underset{\rightarrow}{F}$) it.

Examples:

Force, Velocity, Torque, Acceleration, Weight, Electric and magnetic fields etc.

Graphical Representation of Vectors:

Another way to represent vectors is graphical method. Graphically, Vectors are represented by an arrow having length equal to magnitudes of Vectors (using proper scale) and the arrow head gives the direction of vectors as shown in the figure below.



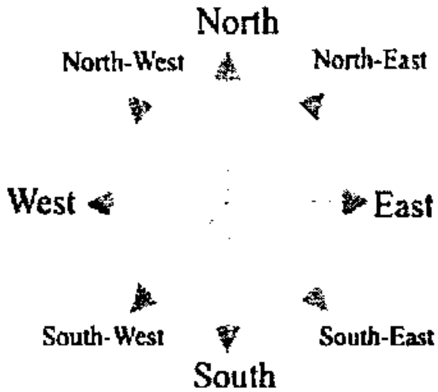
Generally, Vectors are represented by graphical method through Geographical coordinate system or Cartesian coordinate system.

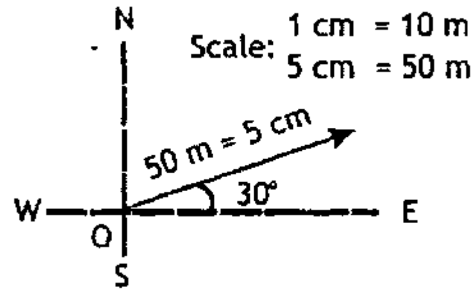
STEPS TO REPRESENT A VECTOR IN COORDINATE SYSTEM

Following is the method used to represent a vector.

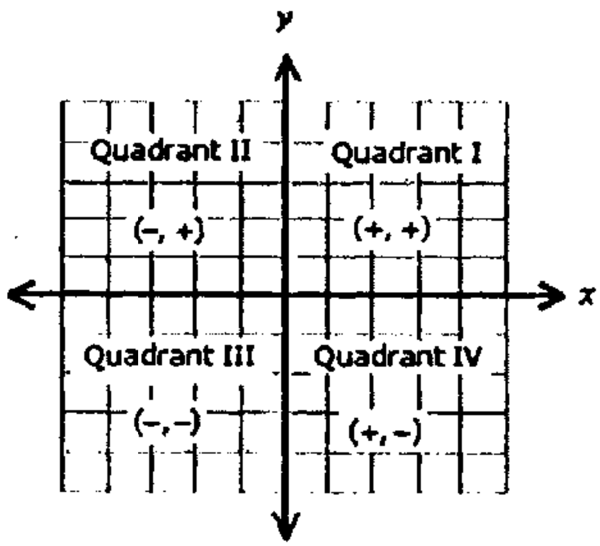
1. Draw your desired coordinate system.
2. Select a proper and suitable scale.
3. Draw a line in the specified direction. Cut the line equal to the magnitude of the vector according to the selected scale.

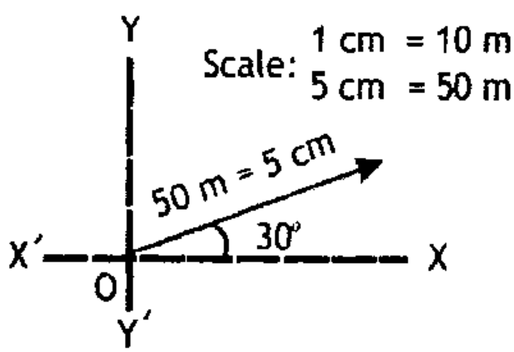
4. Put an arrow in the direction of the vector as shown below.





Geographical Coordinate System



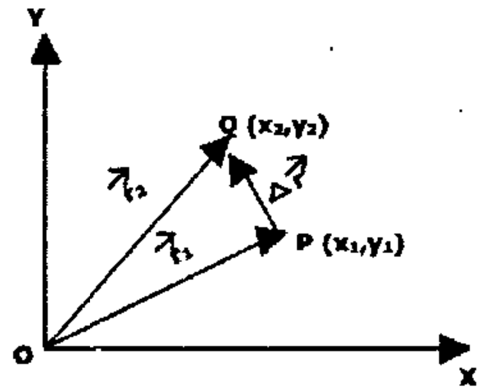


Cartesian Coordinate System

Q.4: What is position? Explain the difference between distance travelled, displacement, and displacement magnitude.

Ans. <u>Position:</u>

A place where someone or something is located or has been put. In Physics position is referred to a point in a coordinate system where an object is located or has to be transferred. For example, points P and Q in below figure represent positions.



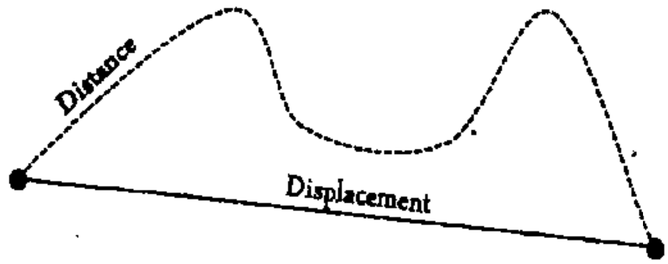
Displacement vectors is ($\Delta\vec{r} = \vec{r}_2 - \vec{r}_1$)
the difference between two position vectors

We use position vectors to represent the position of a point which is drawn from the reference point (origin o) to the point in a coordinate system as shown in above figure by $\vec{r}_1$ and $\vec{r}_2$.

Difference between distances travelled, Displacement and Displacement magnitude:

<u>Distance and Displacement:</u>

The actual path followed by a body during motion is called as distance while the shortest distance between two points is called as displacement as shown in the below figure for two points A and B.



Distance is a scalar quantity while displacement is a vector. Distance and displacement can have same numerical value (magnitude), the only difference is that distance has no direction where as displacement has proper direction (Either from A to B or from B to A in above figure) Displacement has two components, its magnitude and direction. The magnitude of Displacement is equal to the shortest distance travelled. We can write that

Distance = Displacement – Direction

Q.5: State and explain the terms:

a. speed **b. velocity** **c. acceleration**

Ans. (a) **Speed:**

The distance travelled by a body per unit time is called as speed. **OR**

The rate of change of distance is called as speed.

Mathematically

$$\text{Speed} = \frac{distance}{time} \text{ or } v = \frac{\Delta s}{\Delta t} \text{ or } v = \frac{S_f - S_i}{t_f - t_i}$$

Whereas V is for speed, S is for Distance and t for time.

Nature and Unit:

As distance is scalar so speed is also a scalar quantity. The SI unit of speed is meter per second (m/s or ms^{-1}).

Speed tells us how fast an object is travelling. For example, Ali starts running from his home to school, which is 20m away from his home. He reaches to school in 10 seconds. So, his speed will be given by

$$v = \frac{20}{10} = 2\ ms^{-1}$$

Average speed:

Total distance travelled by a body in total time is called as average speed.

Mathematically

$$<v> = \frac{Total\,distance}{Total\,time} \text{ or } <v> = \frac{s}{t}$$

For example, total distance between Peshawar and Karachi is 1360 km and a car takes 20 hours to reach. We will calculate average speed as follows

$$\text{Average speed} = \frac{1360}{20} = 68\ km\ h^{-1}$$

Instantaneous Speed:

The speed of a body at very instant (short interval) is called as instantaneous speed.

Mathematically, $v = \lim\limits_{\Delta t \to \infty} \frac{\Delta s}{\Delta t}$

The Limit Δt approaching to ZERO, (close to zero but not zero) indicates that we are observing the change in distance in a time as small as possible. This is the speed the speedometer of our car shows, which keep track of changes in speed within a fraction of a second.

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Uniform and variable speed:

4 *If speed of a body remains uniform i.e. a body travels equal distances in equal intervals of time, then the speed of the remains unchanged and is called as uniform speed.* For example, a runner completes each cycle around a cricket ground in 5 minutes then we say that speed of the runner is uniform.

Similarly, if speed of a body changes with time i.e. a body travels unequal distances in equal intervals of time or equal distances in unequal intervals of time, then speed of the body changes and is called as variable speed. For example, the same runner completes one cycle around the ground in 5 min, then in 5.2 min, then 5.4 min and then in 5.1 min. Each time his speed varies which means he is travelling with variable speed.

TABLE 2.2: TYPICAL SPEED VALUES

Item	speed (m/s)	speed (km/h)
Continental drift.	3×10^{-10}	1×10^{-9}
Moon receding from the Earth	1.3×10^{-9}	4.68×10^{-9}
Growth rate of bamboo	1.4×10^{-5}	5.0×10^{-5}
Comfortable bicycling speed.	6-7	20-25
Car (freeway); cheetah	30	110
Fastest recorded ball speed (a golf ball)	91	328
Wind speed of a powerful tornado	130	468
Muzzle velocity of M16 rifle	975	3510
Speed of the Earth in orbit around Sun.	29,800	107,280
Speed of light, fastest speed	299,792,458	1.1×10^{9}

(B) VELOCITY:

The displacement travelled by a body in unit time is called as velocity. OR *The time rate of displacement is called as velocity.*

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Mathematically

$$\text{Velocity} = \frac{displacement}{elapsed\,time} \text{ or } \overline{V} = \frac{\Delta \vec{s}}{\Delta t}$$

$$\text{or } \overline{V} = \frac{\vec{S}_f - \vec{S}_i}{t_f - t_i}$$

Nature and Unit:

As displacement is vector so velocity is also a vector quantity. The SI unit of velocity is meter per second (m/s or ms^{-1})

Average velocity:

Total displacement travelled by a body in total time is called as average velocity.

Mathematically

$$<v> = \frac{Total\,displacement}{Total\,time} \text{ or } <v> = \frac{s}{t}$$

Instantaneous Velocity:

The velocity of a body at very instant (short interval) is called as instantaneous velocity.

Mathematically

$$\vec{V} = \lim_{\Delta t \to 0} \frac{\Delta \vec{s}}{\Delta t}$$

A body is said to have uniform velocity if its average and instantaneous velocity become equal. Otherwise it is non uniform.

(C) ACCELARATION:

The rate of change of velocity is called as acceleration. As velocity has magnitude as well as

direction so, acceleration can be produced by changing magnitude of velocity only, direction of velocity only or both.

Mathematically

$$\text{Acceleration} = \frac{\textit{change in velocity}}{\textit{elapsed time}} \text{ or } \vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

$$\text{or } \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

Acceleration is also a vector quantity having same direction as change in velocity. SI Unit of acceleration is meter per second squared (m/s^2).

Note: Acceleration is a measure of how rapidly the velocity is changing.

Average acceleration:

Dividing total change in velocity by total time elapsed give us average acceleration.

Mathematically,

$$\langle a \rangle = \frac{\textit{Total change in velocity}}{\textit{Total time}} \text{ or } \langle a \rangle = \frac{\Delta\vec{v}}{\Delta t}$$

Instantaneous Acceleration:

Acceleration at particular instant of time is known as instantaneous acceleration. Instantaneous acceleration is obtained if Δt is made smaller and smaller such that it approaches to ZERO given by

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta\vec{v}}{\Delta t}$$

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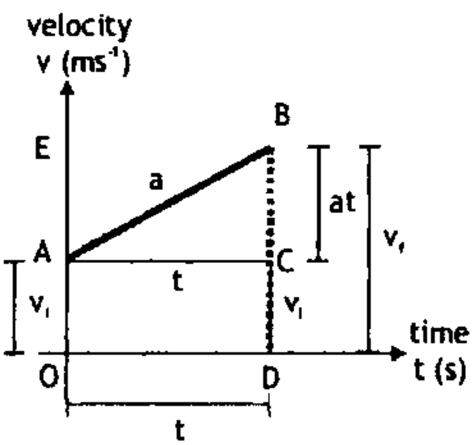
		Example
Positive & increasing (getting more positive)	**Positive:** Particle is moving in +x-direction & speeding up	$t_i = 0$ s, $v_i = 5$ m/s; $a = 2\ m/s^2$; $t_f = 5$ s, $v_f = 15$ m/s
Positive & decreasing (getting less positive)	**Negative:** Particle is moving in +x-direction & slowing down	$t_i = 0$ s, $v_i = 15$ m/s; $a = -2\ m/s^2$; $t_f = 5$ s, $v_f = 5$ m/s
Negative & increasing (getting less negative)	**Positive:** Particle is moving in -x-direction & slowing down	$t_f = 5$ s, $v_f = -5$ m/s; $a = 2\ m/s^2$; $t_i = 0$ s, $v_i = -15$ m/s

Deceleration/Retardation:

If the magnitude of velocity is decreasing with time then change in velocity is negative and acceleration also becomes negative called Retardation or Deceleration. The above table explains difference between acceleration (positive) and deceleration (negative).



UNIFORM ACCELERATION:

If change in velocity of a body is uniform in time then we say that acceleration is uniform. **OR**

A body is said to have uniform acceleration if its average and instantaneous acceleration becomes equal.

Q.6: Use velocity-time graph to prove the following equations of motion:

(a) $v_f = v_i + at$

(b) $\mathbf{s = v_i t + \frac{1}{2}at^2}$

(c) $\mathbf{2as = v_f^2 - v_i^2}$

Ans. We chose the initial time to be zero $t_i = 0$, and final time $t_f = t$ such that $\Delta t = t_f - t_i = t - 0 = t$. Also, we chose initial position to be zero $s_i = 0$ and final position $s_f = s$, such that displacement $\Delta s = s_f - s_i = s - 0 = s$.

The object has initial velocity v_i at point A, which changes uniformly to point B as v_f. In the plot OA = DC represents initial velocity v_i and DB represent final velocity v_f. Here time t is represented by OD = AC= t.

The slope of the line AB is

$$\text{Slope} = \frac{\overline{CB}}{\overline{AC}}$$

The slope of velocity-time graph gives acceleration a, since AC = t, therefore

$$a = \frac{\overline{CB}}{t} \text{ or } \overline{CB} = at$$

(a) $\mathbf{v_f = v_i + at}$

First equation of motion gives the relation of final velocity v_f in terms of initial velocity v_i and acceleration a in time t. From the graph it is clear that

$$\overline{DB} = \overline{DC} + \overline{CB} \text{ -------1}$$

From above diagram

$\overline{DB} = v_f$, $\overline{DC} = v_i$ and $\overline{CB} = at$

Putting these values in equation 1

$$v_f = v_i + at$$

(b) $s = v_i t + \frac{1}{2} at^2$

Second equation of motion relates displacement s with initial velocity v_i and acceleration a in time t. As the area under velocity-time curve represents the displacement s. Therefore, the displacement s of the object is:

Displacement S = Area of rectangle OACD + Area of Triangle ACB

$$s = \overline{OA} \times \overline{AC} + \frac{1}{2} \times (\overline{AC} \times \overline{BC})$$

From above diagram

$AC = t$; $OA = v_i$ and $CB = at$

$$s = v_i \times t + \frac{1}{2} \times (t \times at)$$

$$s = v_i t + \frac{1}{2} at^2$$

(c) $2as = v_f^2 - v_i^2$

Third equation relates position s, velocity v (both final velocity v_f and initial velocity v_i), and constant acceleration a without including time t. The area under the curve can be calculated by taking the total area of the trapezium OABD.

The area of a trapezoid OABD will give the total displacement.

$$S = \frac{1}{2} (\overline{OA} + \overline{DB}) \times \overline{OD}$$

Here $DB = v_f$, $OA = v_i$ and $OD = t$

Putting values $s = \frac{1}{2} (v_i + v_f) \times t$

From 1st equation of motion

$v_f = v_i + at$

$at = v_f - v_i$ or $t = \frac{v_f - v_i}{a}$

The above equation becomes

$$s = \frac{1}{2}(v_i + v_f) \times \frac{v_f - v_i}{a}$$

$$s = \frac{1}{2a}(v_i + v_f) \times (v_f - v_i)$$

$$s = \frac{v_f^2 - v_i^2}{2a}$$

Therefore, $2as = v_f^2 - v_i^2$

Q.7: What is free-fall? What is its value near the surface of earth? Explain with example that rock and sheet of paper will fall at the same rate without air resistance.

Ans. **Free Fall:**

The motion, in which air resistance is neglected and the acceleration is nearly constant, is known as free-fall.

Explanation:

Near the earth's surface, g is approximately

$g = 9.8 ms^{-2} = 32.2\ fts^{-2}$

This value of free-fall acceleration is constant near the surface of earth and above up to a distance of 100 km. After that a change in value of "g" starts and continuously decrease as shown in the table gives.

Location	Distance from Earth's center (m)	Value of g m/s^2
Earth's surface	6.38×10^6 m	9.8
1000 km above surface	7.38×10^6 m	7.33
5000 km above surface	1.14×10^7 m	3.08
10000 km above surface	1.64×10^7 m	1.49
50000 km above surface	5.64×10^7 m	0.13

Mathematically, $g \propto \frac{1}{r^2}$

$$g \propto \frac{1}{(R_E + h)^2}$$

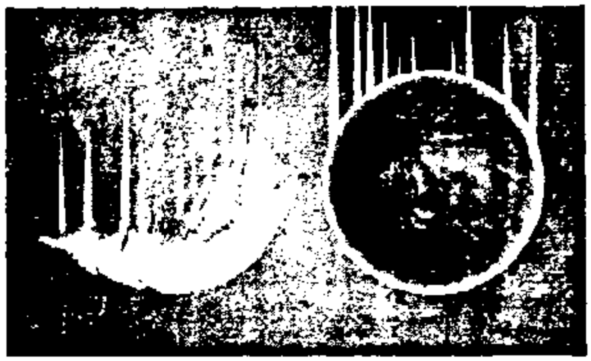
Whereas R_E is radius of earth and "h" is distance from earth's surface. So, when "h" increases value of free-fall (g) decreases.

Rock and feather:

From above equation it is clear that value of "g" depends upon the distance from the earth's surface and is independent of the mass of the falling body. If, it is vacuum they will fall at the same rate. Otherwise, in air, it is air resistance that causes the ball fall quickly than feather. The air resistance on feather is high which causes it to fall slowly.

When an object moves in the direction of gravity, acceleration due to gravity is taken as positive (+g) and

when object moves against gravity, acceleration due to gravity is taken negative (–g).



EXAMPLES AND ASSIGNMENTS

EXAMPLE 2.1

SPEED OF SNAIL:

In the Guinness Gastropod Championship, the fastest speed for garden snail was recorded. The snail covered 330-millimetre distance in 2 minutes and 20 seconds; what was the speed of snail?

Solution:

Given

Distance covered $\Delta s = 330$ mm

$= 330 \times 10\text{m} = 0.330\text{m}$

Total time t = 2 min and 20s = $(2 \times 60 \text{ s}) + 20$

s = 140 s

Required Speed v =?

Average speed is given by

$$<v> = \frac{Total\,distance}{Total\,time} \text{ or } <v> = \frac{s}{t}$$

Putting values

$$< v > = \frac{0.330}{140}$$

$$\boxed{< v > = 0.0024 \text{ m/s} = 2.44 \text{ m/s}}$$

The world record speed for a garden snail is only 0.0024m/s (0.000066km/h) at this speed it will take nearly five days for a garden snail to move constantly through 1 km.

EXTENSION EXERCISE 2.1:

Hint: speed of snail varies.

ASSIGNMENT 2.1:

FASTEST MAN

In 2009 a Jamaican sprinter Usain Bolt created a World Record in Berlin by running 100m in just 9.58 s. What is his average speed?

Solution:

$$\text{Average speed} = < V > = \frac{100}{9.58} = \boxed{10.4 \text{ m/s}}$$

EXAMPLE 2.2

STRAIGHT ROAD

A straight track is 1200 m in length. A runner begins at the starting line, runs due east for the full length of the track, turns around and runs halfway back. The time for this run is five minutes. What is her (a) average velocity, and (b) average speed?

Solution:

GIVEN:

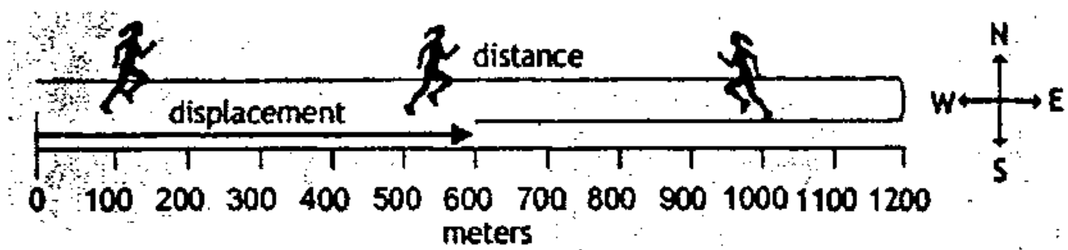
Distance covered $\Delta s = 1200m + 600m = 1800m$

Displacement $\Delta s = 1200\ m - 600\ m = 600\ m$

Required: (a) average speed <v> =?

(b) average velocity <v> =?

time $\Delta t = 5\ min = (5 \times 60\ s) = 300\ s$



(a) From the definition of average velocity

$$<\bar{v}> = \frac{Total\,displacement}{Total\,time} \text{ or } <\bar{v}> = \frac{s}{t}$$

Putting values $<\bar{v}> = \dfrac{600m\,(east)}{300s}$

Therefore, $\boxed{<\bar{v}> = 2\text{ m/s (E)}}$

(b) From the definition of average speed, we have

$$<v> = \frac{Total\,distance}{Total\,time} \text{ or } <v> = \frac{s}{t}$$

Putting values $< v > = \dfrac{1800m}{300s}$

$\boxed{< v > = 6\text{ m/s}}$

ASSIGNMENT 2.2:

AVERAGE VELOCITY OF COMPLETE LAP

A runner makes one lap around a 270m circular track in 30s. What is his (a) average speed and (b) average velocity?

Solution:

(a) Average Speed = $\frac{Total\,distance}{Total\,time} = \frac{270m}{30s}$

$$\boxed{\langle v \rangle = 9\text{ m/s}}$$

(b) Average Velocity = $\frac{Total\,displacement}{Total\,time}$

As the runner starts motion from a point and reaches back to his initial position by completing one round, so his displacement is zero. Therefore

$$\boxed{\text{Average Velocity} = 0}$$

EXAMPLE 2.3

ACCELERATION OF CAR

You observe that your car accelerates from rest to 140 km/h in just 17.6 seconds on straight road towards east. What is the acceleration of your car?

Solution:

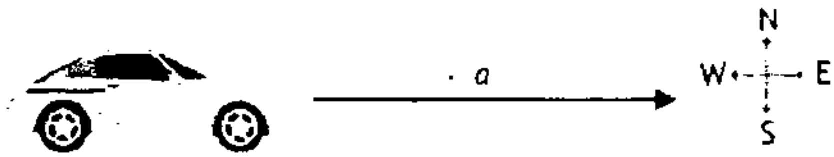
Given:

Initial velocity V_i = 0 km/h East = 0 m/s

Required: East acceleration a =?

Final velocity V_f=140km/h East=38.88m/s East

Time elapsed Δt = 17.6 s



Acceleration is given by

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}} \text{ or } \vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

$$\text{or } \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

Putting values

$$a = \frac{(38.88-0)m/s}{17.6s}$$

$$\boxed{a = 2.21 \text{ m/s}^2 \text{ \{in the direction of East\}}}$$

Hint for Extension exercise 2.2:

Then acceleration will be opposite to East and will be towards West.

ASSIGNMENT 2.3:

INSTANTANEOUS ACCELERATION

If in the same experiment you take the readings of the speedometer of the car as 20 km/h in the 4th second and 32 km/h in the 9th second. What is the acceleration of your car in this interval?

Solution:

Given:

Initial Velocity $v_i = 20\text{km/h} = \frac{20\times1000}{3600} = 5.56\text{m/s}$

Required: Acceleration a =?

Final Velocity $v_f = 32$ km/h $= \dfrac{32 \times 1000}{3600}$

$= 8.89$ m/s

Time t = 9 - 4 = 5 s

Using 1st equation of motion

$v_f = v_i + at$

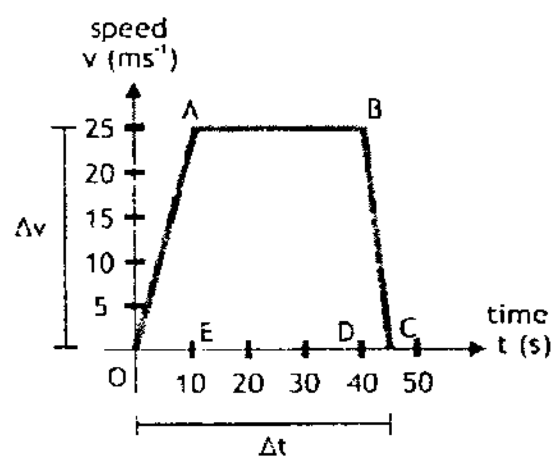
$a = (v_f - v_i) / t$

$a = (8.89 - 5.56) / 5 = \boxed{0.66 \text{ m/s}^2}$

EXAMPLE 2.4

GRAPHICAL ANALYSIS OF CAR'S SPEED

A car increases its speed from ZERO to a 25m/s in 10s. Then it moves with uniform speed for the next 30 seconds and then the driver apply brakes and the speed of the car decreases uniformly to ZERO in the next 5 seconds. The graph is plotted for the journey, use this graph to calculate:



(a) magnitude of acceleration (i) in first 10s
(ii) from 10s to 40s and (iii) in last 5 seconds

(b) total distance covered

(c) average speed

(a) The slope of the graph will give magnitude of acceleration.

$$\text{Slope} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \text{magnitude of acceleration}$$

(i) For the first 10 seconds, OA line represents the slope

Magnitude of acceleration =

$$|\vec{a}| = \frac{25\frac{m}{s} - 0\frac{m}{s}}{10s - 0s} = \frac{\frac{25m}{s}}{10s} = \boxed{2.5 \text{ m/s}^2}$$

(ii) From 10 s to 40 s, the slope is represented by line AB

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{25\frac{m}{s} - 25\frac{m}{s}}{40s - 10s} = \frac{\frac{0m}{s}}{30s}$$

$$= \boxed{0 \text{ m/s}^2}$$

(iii) In the last 5 seconds

$$\text{Magnitude of acceleration} = |\vec{a}| = \frac{0\frac{m}{s} - 25\frac{m}{s}}{45s - 40s} = \frac{-\frac{25m}{s}}{5s}$$

$$= \boxed{-5 \text{ m/s}^2}$$

In the first 10 s the car's acceleration is $2.5 m/s^2$, from 10s to 40s it is $0 m/s^2$, while in the last 5s it is $-5 m/s^2$. the negative gradient indicates the car is slowing down.

(b) Now the total distance covered is equal to the area under the speed-time graph.

Total distance = Area of triangle OBE + Area of rectangle ABDE + Area of triangle CBD

$$S=\{\frac{1}{2}\times(25ms^{-1}\times10s)\}+\{25ms^{-1}\times30s\}+\{\frac{1}{2}\times(25ms^{-1}\times5s)\}$$

Or s = 125m + 750m + 62.5 m = $\boxed{937.5\text{ m}}$

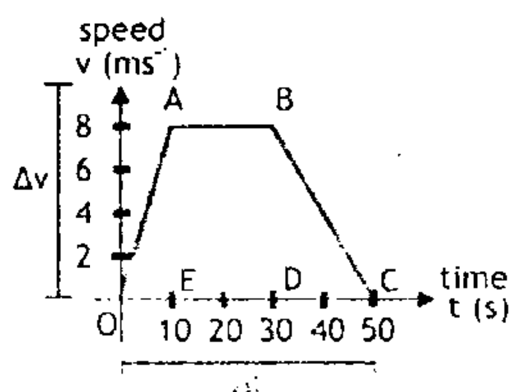
(c) Now the average speed can be calculated when distance s is divided by total time t.

$$\text{Average Speed} = \frac{Total\,distance}{Total\,time} = \frac{937.5m}{45s} \boxed{= 20.8\text{ m/s}}$$

ASSIGNMENT 2.4

GRAPHICAL ANALYSIS OF CYCLIST

A cyclist increases his speed from ZERO to 8 m/s in 10 s. Then he moves with uniform speed for the next 20 seconds and then its speed decreases uniformly to ZERO in the next 20 seconds. The graph is plotted for the journey, use this graph to calculate the total distance covered.



Solution:

5 Distance covered=Area under the speed-time graph.

S = Area of triangle OAE + Area of Rectangle ABDE + Area of triangle BDC

$S = A_1 + A_2 + A_3$

i. $A_1 = \frac{1}{2} \times AE \times OE = \frac{1}{2} \times 8 \times 10 = 40$ m

ii. $A_2 = ED \times AE = 20 \times 8 = 160$ m

iii. $A_3 = \frac{1}{2} \times BD \times DC = \frac{1}{2} \times 8 \times 20 = 80$ m

Total distance = 40 + 160 + 80 = $\boxed{280 \text{ m}}$

EXAMPLE 2.5

SPEEDING MOTORCYCLIST

A motorcyclist starts from rest and moves with uniform acceleration of 1.4 m/s^2 for 12 s. Find the (a) velocity and (b) distance covered?

Solution:

Given:

initial velocity v_i = 0 km/h = 0 m/s

acceleration a = 1.9 m/s^2

Total time t = 22 s

Required:

(a) final velocity v_f =?

(b) Distance S =?

(a) To find final velocity we can use the first equation of motion

$v_f = v_i + at = 0 + (1.9 \times 22) = \boxed{41.8 \text{ m/s}}$

(b) For the distance covered, we will use second equation of motion

$$s = v_i t + \frac{1}{2}at^2$$

Putting values

$$s = 0ms^{-1} \times 22ms^{-1} + \frac{1}{2}1.9ms^{-2} \times (22s)^2$$

$$\boxed{s = 459.8 \text{ m}}$$

Extension Exercise: 2.3:

Hint: $v = 41.8ms^{-1} = \frac{41.8 \times 3600}{1000} = 150.5kmh^{-1}$

A very high speed and is most dangerous. Even on motorway for cars, the maximum speed is 120kmh^{-1}.

$$s = \frac{v_f^2 - v_i^2}{2a} = \frac{41.8^2 - 0^2}{2 \times 1.9} = \boxed{459.8m}$$

ASSIGNMENT 2.5: CYCLIST MOTION

A cyclist is moving with uniform acceleration of 1.2 m/s^2. How much time will it require to change his velocity from 6 m/s to 12 m/s.

Solution:

Given:

initial velocity v_i = 6 m/s

final velocity v_f = 12 m/s

acceleration a = 1.2 m/s^2

Required: Time = t =?

Using first equation of motion to find time

$v_f = v_i - at$

$$t = \frac{v_f - v_i}{a}$$

$$t = \frac{(12-6)}{1.2}$$

$\boxed{t = 5\ s}$

EXAMPLE 2.6

COMMERCIAL AIRCRAFT RUNWAY LENGTH

A Boeing 777 aircraft takes off at 295km/h after accelerating from rest at 2.80 m/s². What is the minimum runway length required?

Solution:

GIVEN: REQUIRED:

initial velocity v_i = 0 km/h = 0 m/s

distance, s =?

final velocity v_f = 295 km/h = 81.9 m/s

acceleration = 2.80 m/s²

We will use the third equation of motion

$$2as = v^2_f - v^2_i$$

$$s = \frac{(v^2_f - v^2_i)}{2a}$$

Putting values

$$s = \frac{(81.9ms^1)^2 - (0ms^1)^2)}{2 \times 2.80ms^2} = \boxed{1197.7875\ m}$$

The units came out correctly as for as displacement (metres) but we have to correct the number and express it in three significant figures.

So, S = 1200 m = 1.20×10^3 m = $\boxed{1.20 \text{ km}}$

EXTENSION EXERCISE 2.4:

Hint: Deceleration is normally smaller than acceleration so, a longer runway is required for landing due to smaller deceleration.

ASSIGNMENT 2.6: BREAKING CAR

On Motorway M_1, a car is moving at speed limit of 120 km/h. By applying brakes, the car comes to rest after covering a distance of 30m. What is the deceleration of the car?

Solution:

Given:

initial velocity v_i = 120 km/h = 33.33 m/s

final velocity v_f = 0 m/s

distance = s = 30 m

Required: deceleration a =?

Using third equation of motion

$2as = v_f^2 - v_i^2$

$$a = \frac{v_f^2 - v_i^2}{2s}$$

Putting values

$$a = \frac{(0)^2 - (33.33)^2}{2 \times 30} = \boxed{-18.5 \text{ m/s}^2}$$

EXAMPLE 2.7

HEIGHT OF BRIDGE FROM WATER SURFACE

A stone is dropped from the Attock Bridge. The stone reaches the water in 3.2s. Find the (a) height of the bridge from water and (b) velocity of the velocity of stone when it strikes the water.

Solution:

Given:

Time t = 3.2 s,

Initial velocity $v_i = 0$ m/s

Acceleration due to gravity g = 9.8 m/s^2

Required: (a) Height h =?

(b) Final velocity v =?

(a) By second equation of motion

$$S = h = v_i t + \frac{1}{2}at^2$$

Putting values

$$h = 0\times 3.2 + \frac{1}{2}\times 9.8\times (3.2)^2 = \boxed{50.176 \text{ m}}$$

(b) By first equation of motion $v_f = v_i + at$

$$v_f = 0 + 9.8 \times 3.2 = \boxed{31.36 \text{ m/s}}$$

ASSIGNMENT 2.7:

CRICKET BALL

In a cricket match ball go straight up with a velocity of 40m/s. Calculate (a) maximum height ball will reach (b) time to reach that height.

Solution:

Given:

Initial velocity $v_i = 40$ m/s

Final velocity $v_f = 0$ m/s

Acceleration due to gravity g = -9.8 m/s^2

Required: (a) Maximum height h =?

(b) Time to reach height t =?

(a) Using 3rd equation of motion

$$2gh = v_f^2 - v_i^2$$

$$h = \frac{v_f^2 - v_i^2}{2a}$$

Putting values

$$h = \frac{(0)^2 - (40)^2}{2\times(-9.8)}$$

$$\boxed{h = 81.6\text{ m}}$$

(b) Using 1st equation of motion

$$v_f = v_i + at$$

$$t = \frac{(v_f - v_i)}{g}$$

Putting values

$$t = \frac{(0-40)}{(-9.8)}$$

$$t = \boxed{4.1\text{ s}}$$

EXERCISE

MULTIPLE CHOICE QUESTIONS

(1) The average speed of a bus is 20m/s, how far can it travel in 10s?

A. 100 m B. 200m

C. 150m D. 250m

(2) A truck accelerates uniformly from 15m/s to 20m/s in 5 s. What is the acceleration of the truck?

A. 2 m/s^2 B. 1.5 m/s^2

C. 1 m/s^2 D. 2.5 m/s^2

(3) A car moving along a straight line at 20 m/s under goes an acceleration of $4m/s^2$. After 2s, its speed will be

A. 28 m/s B. 16 m/s

C. 12 m/s D. 8 m/s

(4) A bird begins to accelerate at a constant 0.3 m/s^2 for 3 s. Its change in velocity is

A. 0.9 m/s B. 1.5 m/s

C. 1.95 m/s D. 2.4 m/s

(5) A car is going backwards at 5 m/s. After 10 s of uniform acceleration, the car is going forward at 10 m/s. The acceleration is

A. 0.5 m/s^2 B. 0.75 m/s^2

C. 1.5 m/s^2 D. 5 m/s^2

(6) The slope of distance-time graph represents:

A. acceleration B. change in acceleration

C. Speed D. distance

(7) The area under a speed-time graph represents:

A. acceleration
B. change in acceleration
C. Distance
D. change in velocity

(8) A student riding his bicycle on a straight flat road covers one block every 7 seconds. If each block is 100m long, he is traveling at:

A. Constant speed
B. Constant velocity
C. 10m/s
D. Both A and B

(9) You drop a rock from a bridge to the river below. When the rock has fallen 4 m, you drop a second rock. As the rocks continue their free fall, their separation

A. Increase
B. Decrease
C. stay the same
D. none

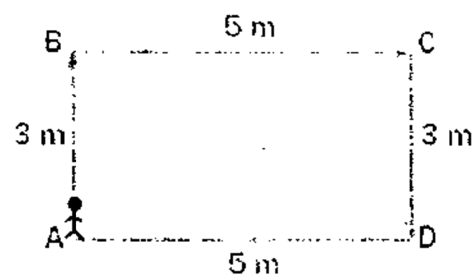
Hint: as acceleration due to gravity is constant.

ANSWERS:

1.B	2.C	3.A	4.A	5.A	6.C	7.C	8.D	9.A	

CONCEPTUAL QUESTIONS

Q.1: Is it possible that displacement is zero but not the distance. Under what condition displacement will be equal to distance.



Ans. Yes, it is possible that displacement is zero but not the distance.

Explanation:

If a body starts motion and finally reaches its initial position then in such a case displacement is zero but not the distance as shown in the figure.

Displacement and distance are equal when the body goes straight from initial point to the final point as shown in the figure. A car moves straight to the school. Here distance and displacement are equal.

Q.2: Does a speedometer measure a car's speed or velocity?

Ans. A speedometer measures a car's speed, not its velocity.

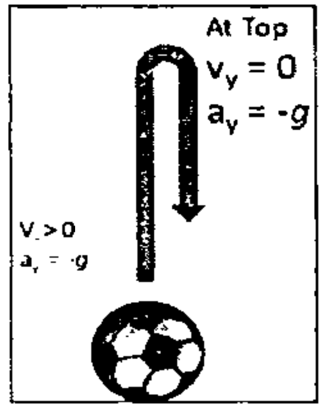
Explanation:

Since the speedometer gives no indication of the direction of the car's motion: It gives same value either you are travelling to North, South, east or West. Therefore, speedometer of car only measures speed of the car and not velocity.

Q.3: Is it possible for an object to be accelerating and at rest at the same time? Explain with example.

Ans. Yes, it is possible for an object to be accelerating and at rest at the same time.

Explanation:



For example, consider an object that is thrown straight up in the air. During its entire trajectory it is accelerating downward. At its maximum height it has a speed of zero. Therefore, at that point it is both accelerating and at rest as shown in the figure.

Q.4: Can an object have zero acceleration and nonzero velocity at the same time? Give example.

Ans. Yes, an object can have zero acceleration and nonzero velocity at the same time.

Explanation:

Whenever an object is travelling with uniform velocity – equal displacements travelled in equal intervals of time – then there is no acceleration produced in the object.

For example, a car is travelling on a straight-line road with 100 km / h velocity.

As, Acceleration = Change in velocity / Time.

Since, velocity is uniform so acceleration = 0.

Q.5: A person standing on the roof of a building throws a rubber ball down with a velocity of 8.0 m/s. What is the acceleration (magnitude and direction) of the ball?

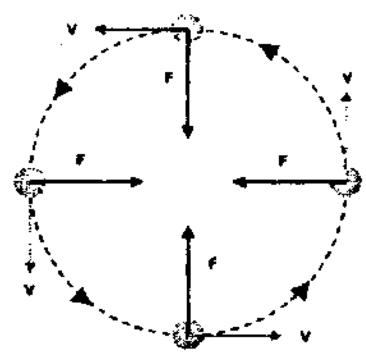
Ans. The only force acting on the ball while it is falling (a free-fall) is that of gravity, so its acceleration is 9.8 m/s^2 and is always directed downward.

Explanation:

Acceleration depends upon force. Here the only force acting on the falling body is its gravity, so, the acceleration will only be due to gravity which is a constant value.

Q.6: Describe a situation in which the speed of an object is constant while the velocity is not.

Ans. When an object is moving and changing its direction, such as uniform motion in a circle then its velocity changes but speed is constant.



Explanation:

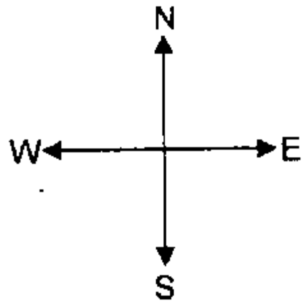
Consider the following figure in which at every point of the circle direction of velocity changes but its magnitude remains constant.

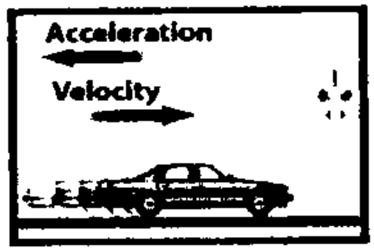
Q.7: Can an object have a northward velocity and a southward acceleration? Explain.

Ans. Yes, an object can have a northward velocity and a southward acceleration

Explanation:

For example, a car that is traveling northward and slowing down has a northward velocity and a southward acceleration.





Q.8: As a freely falling object speeds up, what is happening to its acceleration - does it increase, decrease, or stay the same?

Ans. If air resistance is negligible, the acceleration of a freely falling object stays the same as the object falls toward the ground.

Explanation:

That acceleration is $9.80 m/s^2$. Note that the object's speed increases, but since that speed increases at a constant rate, the acceleration is constant.

Q.9: A ball is thrown upward with an initial speed of 5 m/s. What will be its speed when it returns to starting point?

Ans. Its speed will be the same (5 m/s) when it returns to its starting point.

Explanation:

When a ball is thrown upward, it moves with a deceleration of $9.8\ m/s^2$ until it reaches to a maximum height and stops there for a moment. When it returns, again it moves under the gravitational acceleration ($9.8\ m/s^2$) that is why when it comes to its starting point it has same speed as earlier.

NUMERICAL PROBLEMS

(1) A squash ball makes contact with a squash racquet and changes velocity from 15 m/s west to 25 m/s east in 0.10 s. Determine the vector acceleration of the squash ball.

Solution:

Given:

Final velocity $v_f = 25$ m/s [E]

Initial velocity $v_i = 15$ m/s [W]

Time t = 0.10 s

Required: Acceleration =?

Acceleration is given by (from first equation of motion)

$$a = \frac{(v_f - v_i)}{t}$$

$$a = \frac{(25(E) - 15(W))}{0.10}$$

$$a = \frac{(25(E) + 15(E))}{0.10} = \frac{40(E)}{0.10} = \boxed{400\ ms^{-2}\ (E)}$$

(2) A golf ball that is initially traveling at 25 m/s hits a sand trap and slows down with an acceleration of –20 m/s². Find its displacement after 2.0 s.

Solution:

Given:

Final velocity $v_f = 0$m/s (As the ball finally stops)

Initial velocity $v_i = 25$ m/s

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Time $t = 2.0$ s

Acceleration $a = -20$ m/s^2

Required: displacement s =?

We will use second equation of motion to find displacement.

$$s = v_i t + \frac{1}{2}at^2$$

Putting values

$$s = 25 \times 2.0 + \frac{1}{2}(-20)(2.0)^2$$

$$s = 50 + \frac{1}{2}(-80)$$

$$s = 50 - 40$$

$$\boxed{s = 10\text{ m}}$$

(3) A bullet accelerates the length of the barrel of a gun 0.750 m long with a magnitude of 5.35×10^5 m/s^2. With what speed does the bullet exit the barrel?

Solution:

Given:

Acceleration $a = 5.35 \times 10^5$ m/s^2

Length $s = 0.75$ m

Initial Velocity $v_i = 0$ (As the bullet is at rest initially)

Required: Final Velocity v_f=?

Here we will use 3rd equation of motion

$2as = V_f^2 - V_i^2$

Putting values

$2 \times 5.35 \times 10^5 \times 0.75 = (V_f)^2 - (0)^2$

$v_f^2 = 802,500\ m^2/s^2$

$$v_f = \frac{\sqrt{802,500}}{1} = \boxed{896\ m/s}$$

(4) A driver is traveling at 18 m/s when she sees a red light ahead. Her car is capable of decelerating at a rate of 3.65 m/s². If she applies brakes when she is only 20.0 m from the intersection when she sees the light, will she be able to stop in time.

Solution:

Given:

Deceleration $a = -3.65\ m/s^2$

Distance, $s = 20\ m$

Initial Velocity $v_i = 18\ m/s$

Final Velocity $v_f = 0$ (As the car stops)

Required: Distance needed to stop S =?

Using 3rd equation of motion

$2as = v_f^2 - v_i^2$

$$s = \frac{(v_f^2)^2 - (v_i^2)^2}{2a}$$

$$s = \frac{(0)^2 - (18)^2}{2 \times (-3.65)} = \frac{-324}{-7.3}$$

$$s = \boxed{44.4\ m}$$

This means that the car will stop after travelling 44.4m of distance while the intersection is only 20m away. So, she will not be able to stop the car at intersection.

(5) An antelope moving with constant acceleration 2 m/s^2 covers crosses a point where its velocity is 5 m/s. After 6.00 s how, much distance it has covered and what is its velocity.

Solution:

Given:

Acceleration $a = 2\ m/s^2$.

Time $t = 6.00\ s$

Initial velocity $v_i = 5\ m/s$

Required: (a) Distance S=?

(b) Final velocity v_f =?

(a) Using 2nd equation of motion

$$s = v_i t + \frac{1}{2}at^2$$

Putting values

$$s = 5 \times 6.0 + \frac{1}{2}(20)(6)^2$$

$$s = 30 + 36 = \boxed{66m}$$

(b) Using 1st equation of motion

$$v_f = v_i + at$$

Putting values

$$v_f = 5 + 2 \times 6 = 5 + 12 = \boxed{17\ m/s}$$

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6 **(6) With what speed must a ball be thrown vertically from ground level to rise to a maximum height of 50 m?**

Solution:

Given:

Deceleration $a = -9.8\ m/s^2$

Maximum Height $h = 50\ m$

Final velocity $v_f = 0$ (As at maximum height the ball comes to rest for a while and then return)

Required: Initial Velocity v_i=?

Using 3rd equation of motion

$2as = v_f^2 - v_i^2$

Putting values

$2 \times (-9.8) \times 50 = (0)^2 - (v_i)^2$

$-980 = -v_i^2$

$v_i = \boxed{31.3\ m/s}$

--❀❀❀--

Unit 3

Dynamics

Q.1: What is force? Describe its unit? Distinguish between contact and noncontact forces?

Ans. **Force:**

An agent which produces or tends to produce rest or motion in a body or which increases or decreases velocity of a body is called as force.

Units:

In MKS system unit of force is newton (N) One Newton force is defined as the amount of force acted upon a body of mass 1kg, which produces acceleration of 1 m/s^2 in a body.

In CGS system, unit of force is Dyne (dyn) One dyne force is defined as the amount of force acted upon a body of mass 1g, which produces acceleration of 1 cm/s^2 in a body.

In FPS system the unit of force is poundal (pdl) One newton force is defined as the amount of force acted upon a body of mass 1 pound (1 lb), which produces acceleration of 1 ft/s^2 in a body.

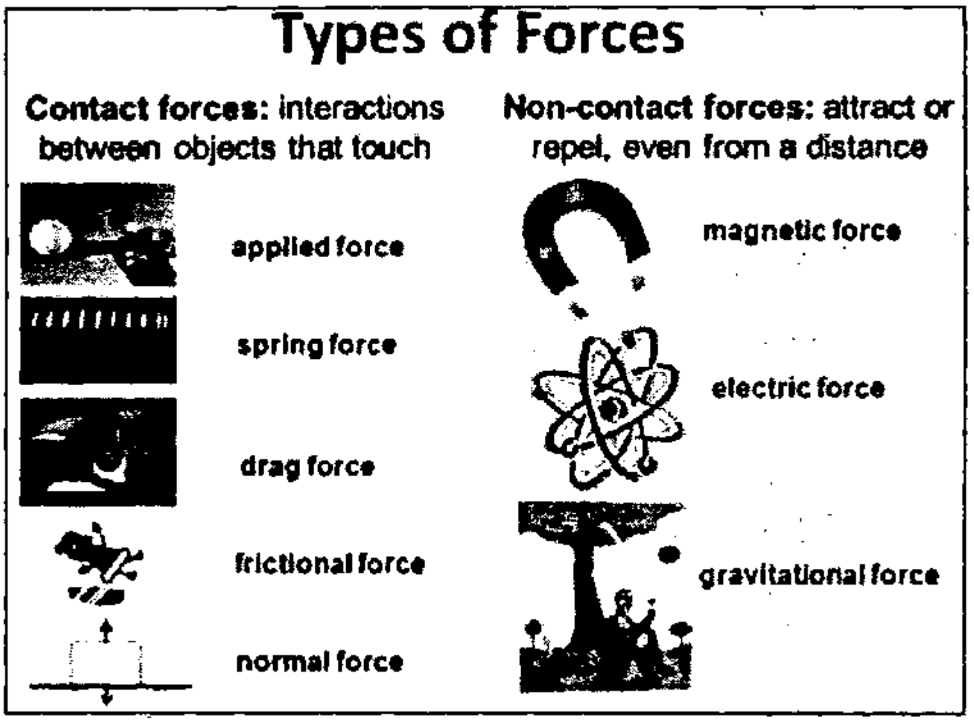
Contact forces:

The types of forces which are in contact with the body are called as contact forces. For example, you kick a football or drag your cupboard in your room.

Noncontact forces:

The type of forces in which there is no direct contact between force and body upon which force is acting are

called as noncontact forces, field forces or action-at-a-distance forces. For example, the gravitational force between earth and sun or the force due to gravity on an apple causes it to fall to ground.



Q.2: State and explain Newton's three laws of motion. Give one example of each.

Ans. *"Newton's laws of motion" provide the basis for understanding the effect that forces have on an object.*

(1) <u>First law of motion:</u>

This law states that whenever there is no net force (the vector sum of all forces) acting on the body, there will be no change in velocity of the body. OR The body at rest will remain at rest and a body in motion will continue its uniform motion forever until and unless a net force acts on the body.

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Mathematically

If $F_{net} = 0$

then $a = 0$ or $V_f = V_i$

Newton's first law indicates that a state of rest (zero velocity) and a state of constant velocity are equivalent, because both of them do not require a net force to sustain it.

Note:

In our common experience when a footballer hits a football, it stops motion after a while, which seems against 1st law of motion. It is not so, the football slows down or stops because there are some resistive forces like air resistance, frictional force and force due to gravity. If all these forces are to be removed then the body will continue its motion for ever.

Inertia:

The ability or tendency of a body to resist or oppose any change in its state of rest or state of motion (to be in the same state either rest or motion) is called as inertia. A book of mass 1 kg can be moved easily but a truck of mass 10,000 kg cannot be moved easily. This means that inertia depends upon mass of a body. Greater the mass greater the inertia will be.

Newton's 1st law of motion and inertia:

As inertia is the tendency of a body to be in the state of rest or motion and 1st law of motion is also about same state (either rest or motion) therefore newton's 1st law of motion is also called as law of inertia.

(2) Newton's second law of motion:

This law states that whenever net force is acting on a body it will change its velocity i.e. will produce acceleration

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in the body. This acceleration is directly proportional to force applied and inversely proportional to mass of the body.

Mathematically

$a \propto F$ 1

$a \propto \frac{1}{m}$ 2

combining equations 1 and 2

$a \propto \frac{F}{m}$

Replacing proportionality sign by constant k

$a = k\frac{F}{m}$

here k = 1, a unitless constant.

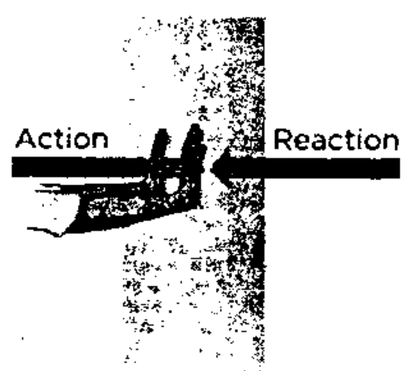
$F = ma$ 3

Newton's second law tells us that a will be larger when F is large and m small.

Equation 3 is mathematical form of Newton's 2nd law of motion.

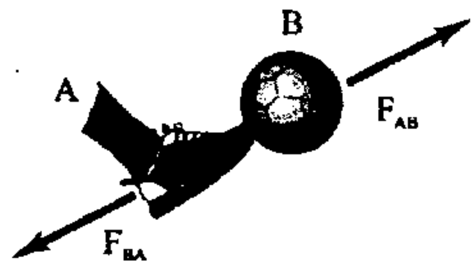
(3) Newton's third law of motion:

This law states that for every action there is an equal but opposite reaction. OR When one object exerts a force on a second object, the second object exerts a force of the same magnitude and opposite direction on the first object.



Consider you push a wall with some force (called action), the wall will also act a force (called reaction) on you which is opposite to the direction of your force as shown in the figure.

Similarly, when a footballer kicks football, he applies action on the ball. Football also applies an opposite force called reaction as shown in the figure.



Mathematically,

$\mathbf{F}_{AB} = -\mathbf{F}_{BA}$

Here the negative sign shows that action and reaction are oppositely directed.

Bold F represents vector of Force.

Both the forces are equal in magnitude i.e.

$F_{AB} = F_{BA}$

Note that action and reaction always occur in pair. They never neutralize each other as both are acting on two different bodies. Here in above example action is on football whereas reaction is on foot.

Q.3: What is weight? Differentiate between mass and weight.

Ans. **Weight:**

The force at which earth attracts every object towards its centre is called as weight. OR *The product of mass (m)*

and acceleration due to gravity ($g = 9.8\ m/s^2$) is called as weight

Mathematically

$$W = mg$$

Here W represents weight of the body.

Unit and nature:

Since weight is force acting on the body by earth so its unit and nature will be same as that of force. SI unit of weight is newton (N) Weight is a vector quantity.

Comparison of Mass and Weight

Mass is a property of matter. The mass of an object is the same everywhere.	Weight depends on the effect of gravity. Weight varies according to location.
Mass can never be zero.	Weight can be zero if no gravity acts upon an object, as in space.
Mass does not change according to location.	Weight increases or decreases with higher or lower gravity.
Mass is a scalar quantity. It has magnitude.	Weight is a vector quantity. It has magnitude and is directed toward the center of the earth or other gravity well.
Mass may be measured using an ordinary balance.	Weight is measured using a spring balance.
Mass usually is measured in grams and kilograms.	Weight often is measured in newton's, a unit of force.

Q.4: Define Linear momentum. Relate force to change in linear momentum.

Ans. **Linear momentum:**

The quantity linear momentum in a body or system is called as momentum. OR *The product of object's mass and its velocity is called as linear momentum.*

Mathematically, p = mv

Nature and Unit:

Linear momentum is a vector quantity having same direction as that of velocity. Unit of linear momentum is kgm/s or Ns.

Explanation:

Generally, a body having greater mass is difficult to stop as compared to smaller mass body if both are moving with same velocity (A truck and bicycle moving with same velocity). Similarly, two equal bodies moving with different velocities, the faster one is difficult to stop as compared to slower one (A billiard ball and Bullet having same masses moving with different velocities).

Relation between force and linear momentum:

Mathematical form of Newton 2nd law of motion is

F = ma 1

Acceleration is defined as rate of change of velocity so,

$$a = \frac{v_f - v_i}{\Delta t} \quad \ldots\ldots 2$$

Putting equation 2 in equation 1

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

$$F = \frac{mv_f - mv_i}{\Delta t} \quad \ldots\ldots 3$$

As mv = p

So $mv_f = p_f$ and $mv_i = p_i$ putting these values in equation 3.

$$F = \frac{p_f - p_i}{\Delta t}$$

$$F = \frac{\Delta p}{\Delta t} \quad \ldots\ldots 4$$

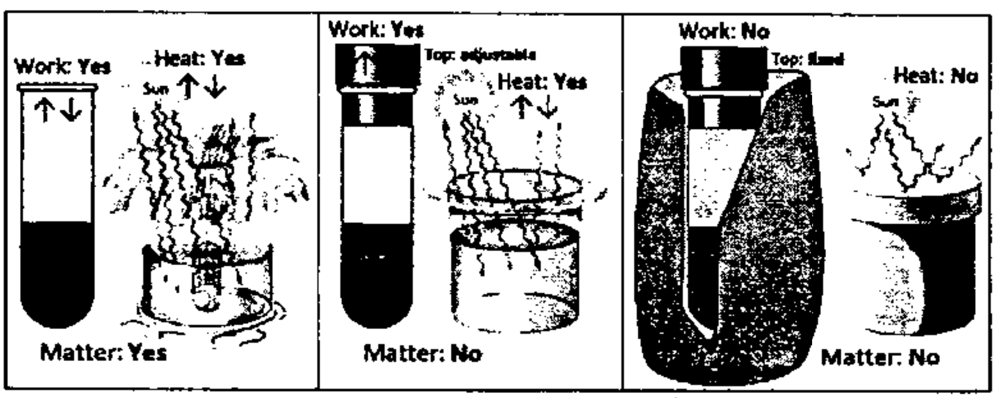
Equation 4 shows that "Force" is equal to the "rate of change of linear momentum".

Q.5: Define isolated system. Explain the law of conservation of momentum.

Ans. **Isolated system:**

The type of system which is completely independent of its environment and observing no change in mass, temperature and size of the system is called as isolated system as shown in the figure.

This type of system is required when we want to study the nature of particles with each other irrespective of the environment. In order to effectively study interactions between particles, we must limit our focus to isolated systems of particles.



Open **Closed** **Isolated**

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Law of conservation of momentum OR 2^{nd} law of motion and conservation of momentum:

This law states that in the absence of external force, linear momentum of a body remains constant or change in momentum is zero.

Mathematically,

$$F = \frac{\Delta p}{\Delta t}$$

If F = 0 then

$$\frac{\Delta p}{\Delta t} = 0$$

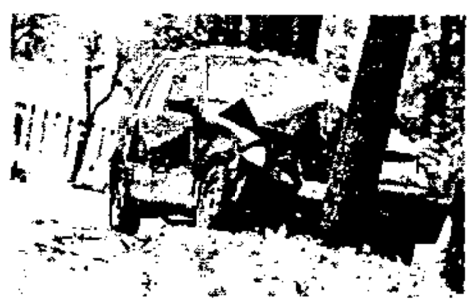
$$\Delta p = 0$$

$$p_f - p_i = 0 \text{ Or } p_f = p_i$$

In the absent of external force (isolated system) the final momentum p_f of the system must be equal to initial momentum p_i. If no net external force acts on a system of particles, the total momentum of the system cannot change.

Q.6: Define collision and explosion. Explain change in momentum in terms of collision and explosion.

Ans. **Collision:**



The type of interaction in which two bodies physically touch each other is called as collision as shown in the figure.

Δp=0 for collision:

Consider two balls of masses m_1 and m_2, moving towards each other with velocities u_1 and u_2 respectively

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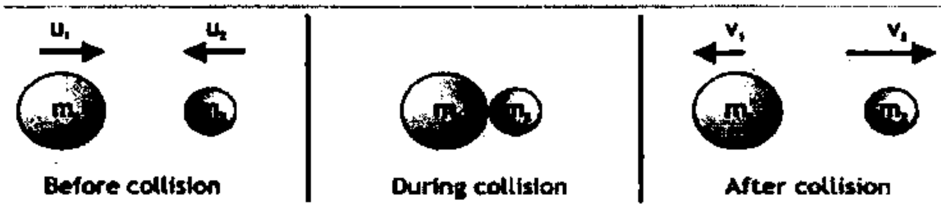
as shown in the figure. After collision both the particles move in opposite directions with new velocities V_1 and V_2.



From law of conservation of momentum

Momentum before collision = Momentum after collision

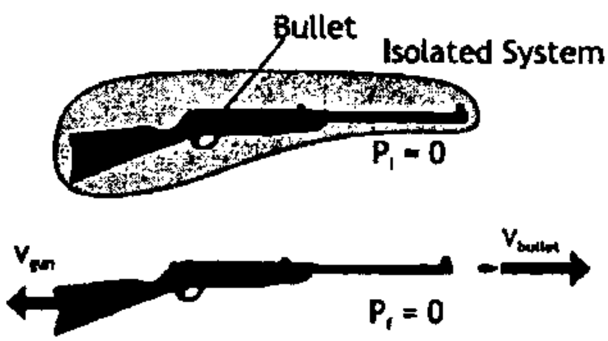
$$p_{BC} = p_{AC}$$

$$m_1u_1 + m_2u_2 = m_1V_1 + m_2V_2$$

Explosion:

The sudden, loud, and violent release of energy that happens when something (such as bomb explosion, firing a bullet from gun) breaks apart in a way that sends parts flying outward. **OR**

The type of interaction in which particles of the system move apart from each other after a brief is called as explosion as shown in the figure.



Δp=0 for explosion:

Given is an isolated system in which initially momentum of the gun plus bullet is zero.

$p_i = 0$

After firing momentum must also be zero as for an isolated system momentum remains conserve. After firing the bullet moves forward with velocity V_b while the gun backward with velocity V_g.The final momentum after firing will be given by

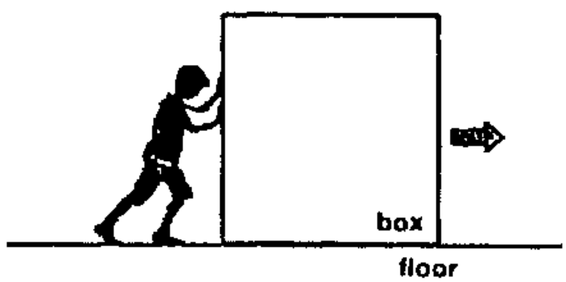
$P_f = m_b V_b + m_g V_g = 0$

As mass of bullet is smaller than rifle, so bullet will move with higher velocity as compared to rifle.

Q.7: What is friction? What are microscopic basis of friction? What is normal force, how it affects friction.

Ans. **Friction:**

Friction is a force that opposes the relative or attempted motion between two surfaces (or systems) that comes to contact with each other. It is denoted by "f" and having unit of newton (N).



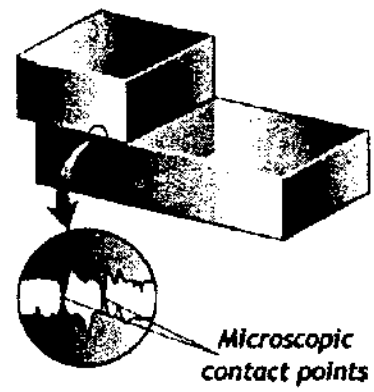
For example, you are pushing a box on the floor. The surface of box and earth comes in contact and a friction force generates between these surfaces as shown in figure.

Similarly, when we rub our hands, friction force warms our hands. Our everyday activities are handled by

friction, without it our life would have been much difficult.

MICROSCOPIC BASIS OF FRICTION:

Every surface is rough, even surfaces that appear to be highly polished can actually look quite rough when examined under a microscope. Some surfaces are rough than others. Therefore, when one surface slide over another, these irregularities bump into one another which give rise to frictional force. Secondly at these contact points the molecules of the different bodies are close enough to exert strong attractive intermolecular forces on each another, thus opposing motion and result in friction.

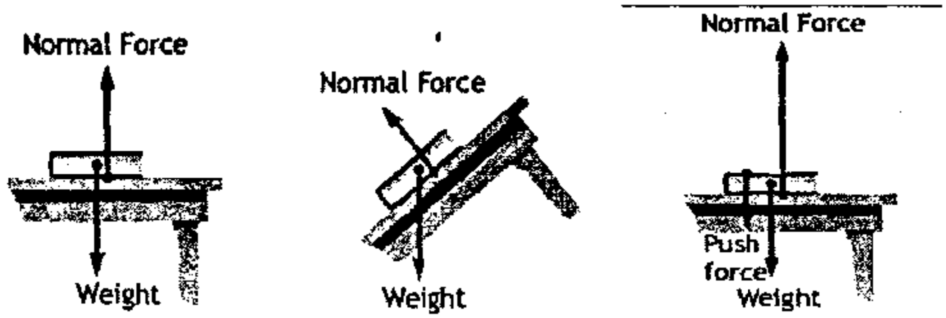


Normal Force:

A contact force perpendicular to the contact surface that prevents two objects from passing through one another is called the normal force F_N. (In geometry, normal means perpendicular.)

Consider a book resting on a horizontal table. By Newton's third law the book exerts force on the table due to its weight and as a reaction table exerts force on the book, which in this case is a normal force. The normal force due to the table must have the right magnitude to keep the book from falling. If no other vertical forces act, the normal force on the book is equal in magnitude to the book's weight. If the surface of the table is not horizontal, then the normal force is not vertical and is not equal in magnitude to the weight of the book. Remember that the normal force is perpendicular to the contact surface.

Even on a horizontal surface, if there are other vertical forces acting on the book, then the normal force is not equal in magnitude to the book's weight as shown in figure.



Effect on friction:

As normal force is equal to weight of the body, so when weight increases frictional force also increases. For example, a brick can easily be moved through a surface while it is difficult to move a cupboard through the same surface.

This means that friction is directly proportional to the normal force. Mathematically

Friction $\propto$ Normal force

$f \propto F_N$

Q.8: Differentiate between static and kinetic friction by giving an example. Find the expression for the coefficient of kinetic and static friction.

Ans. *There are two types of frictions called static friction and kinetic friction as explained below.*

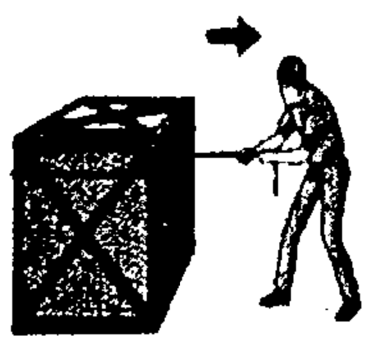
Static friction:

The frictional force that tends to prevent a stationary object from starting motion is called static friction denoted by f_s.

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

[a] All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

For example, when we push horizontally a heavy box. The box does not move. It means that a second force act on the box to oppose our force, and this force must be directed opposite to our applied force and have the same magnitude to balance our push. That second force is a frictional force. When we push even harder, the box still does not move. It means that the frictional force can change in magnitude so that the two forces still balance. Now if we push with more strength. The box begins to slide. So, we can say that, there is a maximum magnitude of



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the frictional force. When we exceeded that maximum magnitude, the box started to move.

Mathematically, $f_{s,max} \propto F_N$ or $f_{s,max} = \mu_s F_N$

Where μ_s is a constant of proportionality known as the coefficient of static friction and depends on the nature of surfaces in contact before sliding.

Kinetic Friction:

The frictional force that acts against motion of an object in a direction opposite to the direction of motion is called kinetic friction. It is denoted by f_k. OR The force that acts between moving surface.

For example, when heavy crate starts motion, kinetic friction f_k now replaces static friction f_s. If we are applying same force the heavy crate after it has started moving it accelerates, means that kinetic friction is less than static friction ($f_k < f_s$). In order to drag the heavy crate with constant velocity we have to reduce the force to make it equal to kinetic friction.

Friction is not restricted to solids sliding or tending to slide over one another. Friction occurs also in liquids and gases, both of which are called *fluids* (because they flow) Fluid friction occurs as an object pushes aside the fluid it is moving through.

Q.9: What are advantages and disadvantages of friction? Also give methods to reduce and improve friction.

Ans. Following are the advantages and disadvantages of friction.

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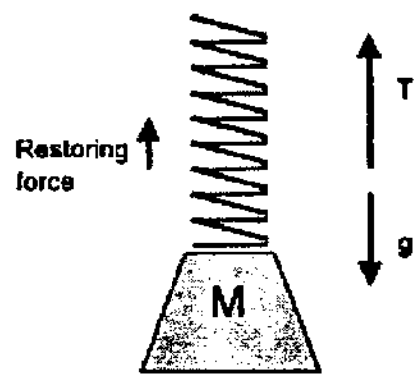
Advantages of friction	Disadvantages of friction
Due to friction, the objects can be placed at position and shaped.	Due to friction, there is wear and tear of objects. Lubrication is used to allow the parts to move easier & to prevent wear and tear. Greasing is done in the moving parts of bicycle.
Frictional forces help to move the object by friction. It helps in running, walking. Frictional force helps to move the object with high speed. For example; spikes are used by the athletes to run fast. Studs in soccer.	Friction makes it more difficult when one has to move the object. Excess friction can make it difficult to slide a box across the floor, walk through deep snow.
With the help of friction, the ridges of skin of our fingers and our palm enable us to grab and hold objects. For example, in badminton the players use grip to hold it.	In the roller skating, rolling shoes and smooth surface are used to minimize friction. Wooden floor used to cycling.
The energy lost due to friction in trying to move the object is turned into heat energy.	Excess of friction means extra energy, thus energy is being wasted.

Q.10: What is tension? If two connected bodies of masses m_1 and m_2 are hanging from the ends of a string which is passing over a pulley (Atwood machine), find the values of tension and acceleration in it.

Ans. <u>Tension:</u>

When two forces are acting on an object pulling against each other, we say the object is in tension.

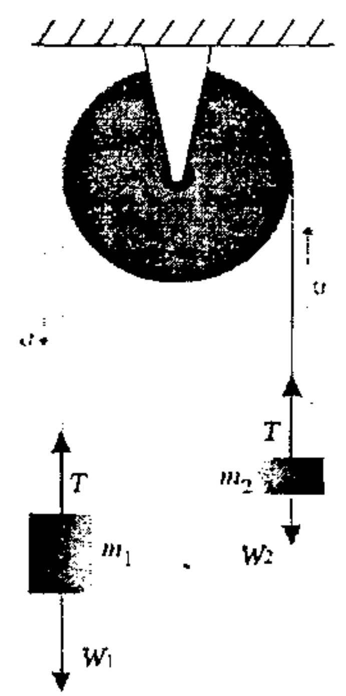
The pulling force exerted by a stretched rope, string, cable or cord on an object to which it is attached is called a tension force. Tension is always a pull force. Hence, the direction of tension force is always the direction in which one would pull the object with a string or rope.



For example, if you have a spring balance held with a weight attached then the spring is in tension. It has the force produced by the weight pulling it one way and the force produced by the arm holding it, pulling it the opposite way.

ACCELERATION AND TENSION IN ATWOOD MACHINE

Consider motion of two objects having masses m_1 and m_2 (with m_1 greater than m_2) suspended by an inextensible string which passes over a frictionless pulley forming an Atwood machine. In such an arrangement m_1 will move downward under the action of gravity and m_2 upward. Tension T and acceleration 'a' will be same for both bodies.



Two forces are acting on mass m_1

Its weight $W_1 = m_1 g$, acting downward

Tension of string T, acting upward.

As 'm_1' is moving downward, the net force F_{net1} acting on it is downward due to which acceleration 'a' is produced in it. Hence,

$$F_{net1} = W_1 - T$$

$$m_1 a = m_1 g - T$$

$$T = m_1 g - m_1 a \quad ....(1)$$

Similarly, two forces are acting on mass m_2

Its Weight $W_2 = m_2 g$, acting downward

Tension of string 'T', acting upward.

As 'm_2' is moving upward, the net force F_{net2} acting on it is upward due to which acceleration 'a' is produced in it. Hence,

$$F_{net2} = T - W_2$$

$$m_2 a = T - m_2 g$$

$$T = m_2 a + m_2 g \quad .... (2)$$

Since both equation (1) and equation (2) equal to T, therefore we can write

$$T = m_2 a + m_2 g = m_1 g - m_1 a$$

Rearranging

$$m_1 a + m_2 a = m_1 g - m_2 g$$

$$(m_1 + m_2)a = (m_1 - m_2)g$$

$$a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g \quad .... (3)$$

This is the value of acceleration at which both masses are moving.

To find the value of tension T, we will put equation (3) in equation (2)

$$T = m_2a + m_2g$$

$$T = m_2\left(\frac{m_1 - m_2}{m_1 + m_2}\right)g + m_2g$$

$$T = m_2g\left(\frac{m_1 - m_2}{m_1 + m_2} + 1\right)$$

$$T = m_2g\left(\frac{m_1 - \cancel{m_2} + m_1 + \cancel{m_2}}{m_1 + m_2} + 1\right)$$

$$T = m_2g\left(\frac{2m_1}{m_1 + m_2}\right)$$

$$T = \left(\frac{2m_1m_2}{m_1 + m_2}\right)g$$

Q.11: What is uniform circular motion? Describe the factors on which magnitude of acceleration (centripetal acceleration) in uniform circular motion depends.

Ans. *When the speed of the moving object does not change as it travels in the circular path, it is called uniform circular motion.*

For example, you are rotating a mass attached to a string over your head in a circle as shown in the figure.

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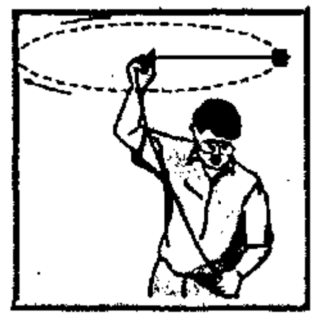
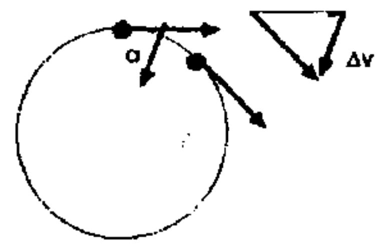
Circular motion is of two types – uniform circular motion and non-uniform circular motion.

Centripetal Acceleration a_c:

Any object moving in a circle (called circular motion) will have an acceleration produced in it, due to the change in direction of velocity. This acceleration is called centripetal acceleration and is always directed toward the centre as shown in the figure.



Uniform circular motion



Centripetal acceleration (ΔV)

Mathematically

$$a_c = -\frac{v^2}{r}$$

The negative sign is because centripetal acceleration is always directed towards the centre.

Factors affecting centripetal acceleration:

Centripetal acceleration depends upon the following factors.

(a) Radius of the circle:

Increasing radius of the circle, centripetal acceleration will decrease i.e. centripetal acceleration is inversely proportional to the radius of circle.

$$a_c \propto \frac{1}{r}$$

(b) Velocity of object:

Increasing velocity of rotating body, centripetal acceleration will increase two times i.e. centripetal

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acceleration is directly proportional to the square of the velocity of body rotating in the circle.

$$a_c \propto V^2$$

Q.12: What is centripetal force? Explain how centripetal force is used in banking of roads and centrifugation.

Ans. **Centripetal Force:**

The force that compels the body to move in a circle or which compels the body to continue its uniform circular motion is called as centripetal force.

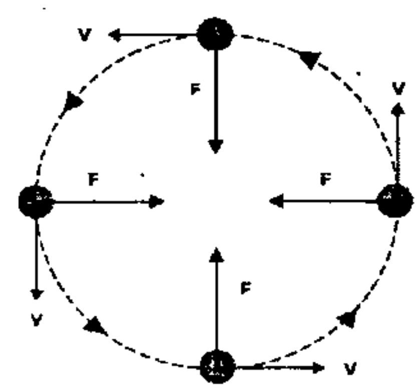
OR

The product of mass and centripetal acceleration is called as centripetal force.

Mathematically

$$F_c = ma_c$$

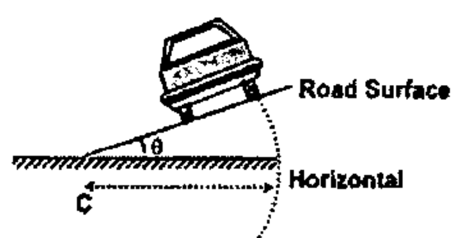
$$F_c = \frac{-mv^2}{r}$$



Negative sign is because centripetal force is always directed towards the centre as shown in the figure.

Centripetal force in banking of roads:

When a car moves along a curve, centripetal force is required. In the absence of this force, the car will skid off the road. The force of friction between the tyre and the road



Banking of roads

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provides this centripetal force and keeps the car moving on the curved path. However, if the tires are worn out or the road is slippery due to some rain, snow or oil spill, the friction will not be enough to provide necessary centripetal force. For extra protection level of the outer edge of a round track is kept slightly higher than that of the inner edge known as banking of road. In this case the normal component of the vehicle increases friction to provide necessary centripetal force for safe turning around the circular track. That is, roads must be steeply banked for high speeds and sharp curves. Since the race car tracks are designed for high speeds, every turn has its own limiting speeds to pass, depending upon banking provided.

Centripetal force in centrifugation:

A centrifuge is a device that separates substances suspended in a liquid by spinning a sample of liquid very quickly around an axle. Any smaller dense particles found in the liquid travel in a straight line inside the test tube, obeying Newton's first law.

The liquid in the test tube applies a centripetal force on these particles to keep them moving in a circle. After running the centrifuge at high speed for a period of time, the particles become clumped together at the bottom of the test tube, which

can be collected and the sample is analyzed as shown in the figure.

EXAMPLES AND ASSIGNMENTS

EXAMPLE 3.1:

FORCES ON SPORTS BALLS

What force is required to produce an acceleration of $6.00 m/s^2$ in a cricket ball of mass m_c 0.16kg and metal ball for women shot-put game with mass $m_s = 4$ kg.

Solution:

Given:

Mass of cricket ball $m_c = 0.16$ kg

Mass of shot-put ball $m_s = 4$ kg

Acceleration $a = 6.00 \ m/s^2$

Required: Force =?

Using mathematical form of Newton's 2nd law of motion

$F = ma$

For cricket ball:

$F = 0.16 \times 6.00 = \boxed{0.96 \text{ N}}$

For shot-put metal ball:

$F = 4 \times 6.00 = \boxed{24 \text{ N}}$

This example shows us that for same acceleration a large force is required for large mass, and small force is required for small mass.

Extension Exercise 3.1: Hint:

Using formula $a = F/m$ and putting values of $F = 10$ N for both masses.

ASSIGNMENT 3.1:

TRUCK AND CAR ACCELERATIONS

Find the acceleration produced by engine force of 3500 N, in car of mass 600 kg and truck of mass 2400 kg.

Solution:

Given:

Mass of Truck $m_T = 2400$ kg

Mass of Car $m_c = 600$ kg

Force F = 3500 N

Required: Acceleration =?

(a) <u>For truck:</u>

$$F = ma \text{ or } a = \frac{F}{m}$$

$$a = \frac{3500}{2400} = \boxed{1.46 \text{m/s}^2}$$

(b) <u>For Car:</u>

$$F = ma \text{ or } a = \frac{F}{m}$$

$$a = \frac{3500}{600} = \boxed{5.8 \text{ m/s}^2}$$

EXAMPLE 3.2:

WEIGHT OF GIRL ON EARTH AND MOON

The mass of a girl is 60 kg. How much will she weight on the (a) Earth? (b) Moon? [take acceleration due to gravity for earth as $g_E = 9.8$ m/s^2 and for moon as $g_M = 1.6$ m/s^2]

Solution:

Given:

Mass of girl m = 60 kg

Acceleration for earth $g_E = 9.8\ m/s^2$

Acceleration for moon $g_M = 1.6\ m/s^2$

Required: (a) Weight on surface of Earth W_E =?

(b) Weight on surface of moon W_M =?

(a) Weight on Surface of Earth:

As W = mg putting values

$W_E = 60 \times 9.8 = \boxed{588\ N}$

(b) Weight on Surface of moon:

As W = mg putting values

$W_M = 60 \times 1.6 = \boxed{96\ N}$

ASSIGNMENT 3.2:

WEIGHT OF ASTRONAUT

The weight of an astronaut and his space suit on the Moon is only 250 N. How much do they weigh on Earth? What is the mass on the Moon? On Earth? [take acceleration due to gravity for earth as g = 9.8 m/s² and moon as g = 1.6 m/s²].

Solution:

Given:

Weight of astronaut on surface of earth= 250N

Acceleration for earth $g_E = 9.8\ m/s^2$

Acceleration for moon $g_M = 1.6\ m/s^2$

Required: (a) Weight on surface of Earth W_E =?
(b) Mass on surface of moon m_E =?
(c) Mass on surface of moon m_M =?

(a) 1st we will find mass of the astronaut from his weight on surface of moon.

W = mg

$$m_m = \frac{W_M}{g_M} = \frac{250}{1.6} = \boxed{156.25 \text{ kg}}$$

As mass is constant anywhere in the universe, so mass on earth's surface will also be 156.25 kg.

Now $W_E = mg_E$

$W_E = 156.25 \times 9.8 = \boxed{1531.25 \text{ N}}$

(b) and (c):

As mass is constant anywhere in the universe, so mass on surfaces of earth and moon will be 156.25kg.

EXAMPLE 3.3: MOMENTUM OF AIRGUN SHOT

An iron shot of mass 6 g is fired with an airgun. If the velocity of the shot is 62 m/s, what is the magnitude of momentum?

Solution:

Given:

Mass of iron shot m = 6g = 0.006 kg

Velocity of shot v = 62 m/s

Required: Magnitude of momentum p =?

From the mathematical form of linear momentum

$p = mv$

$p = 0.006 \times 62 = \boxed{0.372\ \text{Ns}}$

ASSIGNMENT 3.3:

FASTEST RECORDED BALL SPEED IN ANY GAME

The fastest recorded speed for a golf ball hit by a golfer is 75.8 m/s (273 km/h). If mass of golf ball is 46 g, what is the magnitude of its momentum?

Solution:

Given:

Speed of golf ball $v = 75.8\ \text{m/s}$

Mass of golf ball $m = 46\ \text{g} = \frac{46}{1000}\ \text{kg} = 0.046\text{kg}$

Required: Momentum of golf ball p =?

From the mathematical form of linear momentum

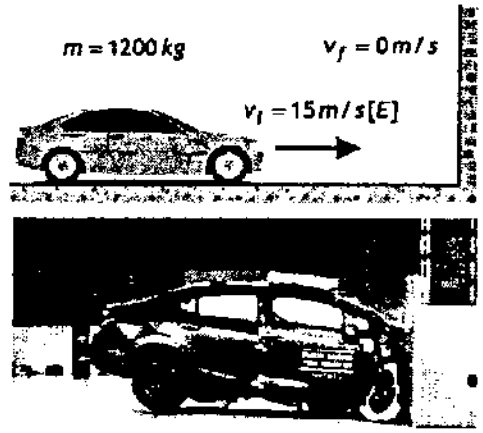
$p = mv$

$p = 0.046 \times 75.8 = \boxed{3.467\ \text{Ns}}$

EXAMPLE 3.4:

IMPACT CRUMPLE OF CAR

To improve the safety of motorists, modern cars are built so the front-end crumples upon impact. A 1200- kg car is travelling at a constant velocity of 15.0 m/s [E]. It hits an immovable wall and comes to a complete stop in 0.25 s.



(a) What is the average net force exerted on the car.

(b) What would be the average net force exerted on the car if it had a rigid bumper and frame that stopped the car in 0.040 s?

Solution:

Given:

Mass of car m = 1200 kg

Velocity of car v = 15 m/s [E]

Time t = 0.25 s, t′ = 0.040 s

Required: (a) Average net force F_{Avg} =?

(b) Force in case of rigid bumper and frame F'_{Avg}=?

(a) By Newton's second law of motion in terms of momentum

$$\vec{F} = \frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t}$$

Putting values

$$\vec{F} = \frac{1200(0-15[E])}{0.25}$$

$$\vec{F} = -72000 \text{ kg m/s [E]}$$

$$\vec{F} = 72000 \text{ kg m/s [W]} = \boxed{7.2 \times 10^4 \text{ kg m/s [W]}}$$

(b) By Newton's second law of motion in terms of momentum

$$\vec{F} = \frac{m(\bar{v}_f - \bar{v}_i)}{\Delta t}$$

Putting values

$$\vec{F} = \frac{1200(0-15[E])}{0.040}$$

$$\vec{F} = -45000 \text{ kg m/s [E]}$$

$$\vec{F} = 450000 \text{ kg m/s [W]} = \boxed{4.5 \times 10^5 \text{ kg m/s [W]}}$$

The average net force exerted by the wall on the car is **(a)** 7.2×10^4N[W] when it crumples and **(b)** 4.5×10^5N[W] when it is rigid. The change in momentum is the same in both parts and is equal to −18000kgm/s, but the time intervals are different. So, the average net force is different in both situations. The magnitude of force on the car with the rigid frame is more than 6 times greater than when the car crumples.

ASSIGNMENT 3.4:

FORCE REQUIRED TO STOP A TRUCK AND CAR

Calculate the force required to stop a car of mass 1200 kg and a loaded truck of mass 9,000 kg in 2 second, if they are moving with same velocity of 10 m/s.

Solution:

Given:

Mass of car $m_c = 1200$ kg

Mass of loaded truck $m_T = 9{,}000$ kg

Initial Velocity $v_i = 10$ m/s

Final Velocity $v_f = 0$ m/s (As both car and loaded truck stops finally)

Time $\Delta t = 2$ s

Required: (a) Force required to stop car F_c =?

(b) Force required to stop F_T truck =?

(a) From the relation between force and momentum

$$F = \frac{\Delta p}{\Delta t} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t} \quad \ldots\ldots\ldots\ldots 1$$

Putting Values in equation 1 for car

$$\vec{F} = \frac{1200\times 0 - 1200\times 10}{2} = \boxed{-6000\text{ N}}$$

(b) Putting Values in equation 1 for loaded truck.

$$\vec{F} = \frac{9000\times 0 - 9000\times 10}{2} = \boxed{-45{,}000\text{ N}}$$

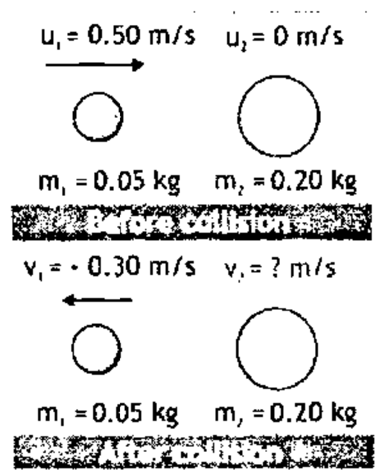
EXAMPLE 3.5:

BALLS COLLISION

Ball 1 having mass 0.05 kg moving to the right at velocity of 0.50 m/s makes a head-on collision with ball 2 having mass 0.20 kg that is initially at rest. After the collision, ball 1 moves to the left at 0.30 m/s. Find the final velocity of the ball 2.

Solution:

Given:



Mass of Ball 1

$m_1 = 0.05$ kg

Mass of Ball 2

$m_2 = 0.20$ kg

Velocity before collision for body 1

$u_1 = 0.5$ m/s

Velocity before collision for body 2

$u_2 = 0$ m/s

Velocity after collision for body 1

$V_1 = 0.30$ m/s

Required: Velocity after collision for body 2, $V_2 = ?$

From law of conservation of momentum

$m_1u_1 + m_2u_2 = m_1V_1 + m_2V_2$

$m_2V_2 = m_1u_1 + m_2u_2 - m_1V_1$

$V_2 = (m_1u_1 + m_2u_2 - m_1V_1) / m_2$

Putting values

$V_2 = [0.05 \times 0.5 + 0.20 \times 0 - 0.05 \times (-0.30)]/0.20$

$\boxed{V_2 = 0.20 \text{ m/s}}$

ASSIGNMENT 3.5:

CAROM BOARD COLLISION

In carom board game the striker of mass having mass 0.015 kg sliding to the right at velocity of 0.40 m/s makes a head-on collision with a disk having

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mass 0.005 kg that is initially at rest. After the collision, striker moves to the right along the direction of disk at 0.20 m/s. Find the final velocity of the disk.

Solution:

Given:

Mass of Striker $m_1 = 0.015$ kg

Velocity of Striker $u_1 = 0.40$ m/s

Mass of disk $m_2 = 0.005$ kg

Velocity of disk before collision $u_2 = 0$ m/s

Velocity of Striker after collision $V_1 = 0.20$ m/s

Required: Velocity of disk after collision $V_2 = ?$

From law of conservation of momentum

$$m_1u_1 + m_2u_2 = m_1V_1 + m_2V_2$$

$$m_2V_2 = m_1u_1 + m_2u_2 - m_1V_1$$

$$v_2 = \frac{(m_1u_1 + m_2u_2 - m_1v_1)}{m_2}$$

Putting values

$$v_2 = \frac{(0.015\times0.40)+(0.005\times0)-(0.015\times0.20)}{0.005}$$

$$\boxed{v_2 = 0.6\text{m/s}}$$

EXAMPLE 3.6:

RECOIL OF AK47

A bullet of mass 0.008 kg is fired from Ak47 rifle with mass of 4 kg. If the velocity of the bullet is 715 m/s, what would be the recoil velocity of the gun?

Solution:

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Given:

Mass of Rifle $m_1 = 4$ kg

Mass of bullet $m_2 = 0.008$ kg

Velocity of Rifle before firing $u_1 = 0$ m/s

Velocity of bullet before firing $u_2 = 0$ m/s

Velocity of bullet after firing $V_2 = 715$ m/s

Required: Velocity of Rifle after firing
(Recoil speed) $V_1 = ?$

From law of conservation of momentum

$m_1u_1 + m_2u_2 = m_1V_1 + m_2V_2$

$m_1V_1 = m_1u_1 + m_2u_2 - m_2V_2$

$$V_1 = \frac{(m_1u_1 + m_2u_2 - m_2V_2)}{m_1}$$

Putting values

$$V_1 = \frac{(4\times0)+(0.008\times0)-(0.018\times715)}{4}$$

$$V_1 = \boxed{-1.43\text{ m/s}}$$

Negative sign is for direction opposite to that of bullet's velocity.

Method#2:

This can also be solved using formula $p_f = p_i = 0$

<u>EXTENSION EXERCISE 3.2 Hint:</u>

No, because then the recoiling speed will be too high to control the rifle.

ASSIGNMENT 3.6:

CANNON RECOIL

A 200kg cannon at rest contains a 10kg cannonball. When fired, the cannon ball leaves the cannon with a speed of 90m/s. What is the recoil speed of the cannon?

Solution:

before firing After firing

Given:

Mass of Cannon $m_1 = 200$ kg

Mass of cannon ball $m_2 = 10$ kg

Velocity of cannon before firing $u_1 = 0$ m/s

Velocity of cannon ball before firing $u_2 = 0$ m/s

Velocity of cannon ball after firing $V_2 = 90$ m/s

Required: Velocity of cannon after firing
(Recoil speed) $V_1 = ?$

From law of conservation of momentum

$$m_1u_1 + m_2u_2 = m_1V_1 + m_2V_2$$

$$m_1V_1 = m_1u_1 + m_2u_2 - m_2V_2$$

$$V_1 = \frac{(m_1u_1 + m_2u_2 - m_2V_2)}{m_1}$$

Putting values

$$V_1 = \frac{(200\times0)+(10\times0)-(10\times90)}{200}$$

$\boxed{V_1 = -4.5 \text{ m/s}}$

Negative sign is for direction opposite to that of bullet's velocity.

Method#2:

This can also-be solved using formula $p_f = p_i = 0$

EXAMPLE 3.7:

WOODEN PACKAGE ON WOOD FRICTION

Ayesha pushes a newly bought deep-freezer of mass 120 kg packed in wood across a wooden floor. (a) She applies a 400 N force to set it moving, what is the coefficient of static friction? (b) Then she makes it move with constant speed by applying force of 350 N, what is the coefficient of kinetic friction?

Solution:

Given:

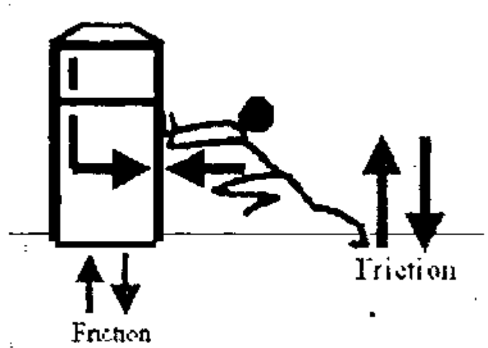
Mass of deep-freezer m = 120 kg

(a) Force applied $f_s = 400$ N

(b) Force applied $f_k = 350$ N

Required: Coefficient of static friction μ_s =?

Coefficient of kinetic friction μ_k =?



Normal force $F_N = W = mg = 120\text{ kg} \times 9.8\text{ m/s}^2$

Normal force $F_N = 1176\text{ N}$

(a) Applied force to set the package moving is equal static frictional force, therefore $f_s = 400\text{N}$, by the relation for coefficient of static friction μs,

$\mu_s = f_s / F_N = 400 / 1176$

$\boxed{\mu_s = 0.34}$

(b) Applied force to keep it moving at constant speed is equal to kinetic frictional force, therefore $f_k = 350$ N, by equation for coefficient of kinetic friction μk,

$$\mu_k = \frac{f_k}{F_N} = \frac{350}{1176}$$

$\boxed{\mu_k = 0.29}$

These values are close to the approximate values given in the table for the coefficient of friction between wood and wood.

ASSIGNMENT 3.7:

LEATHER AND WOOD FRICTION

A 5 kg heavy leather bag is placed on a horizontal wooden plank. How much force is required to set it in motion if the coefficient of friction between the plank and bag is 0.1?

Solution:

Given:

Mass of leather bag m = 5 kg

Coefficient of friction $\mu = 0.1$

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Normal force $F_N = W = mg = 5\ kg \times 9.8\ m/s^2$

Normal force $F_N = 49\ N$

Required: Force f =?

$f = \mu F_N$

$f = (0.1)(49)$

$f = 4.9\ N = \boxed{5\ N}$

EXAMPLE 3.8

ELEVATOR (AS ATWOOD MACHINE)

Let the elevator is going up with mass of counter weight as 1200 kg. Assume the mass of the elevator when carrying passengers is 1000 kg. Calculate (a) the acceleration of the elevator and (b) the tension in the cable.

Solution:

Given:

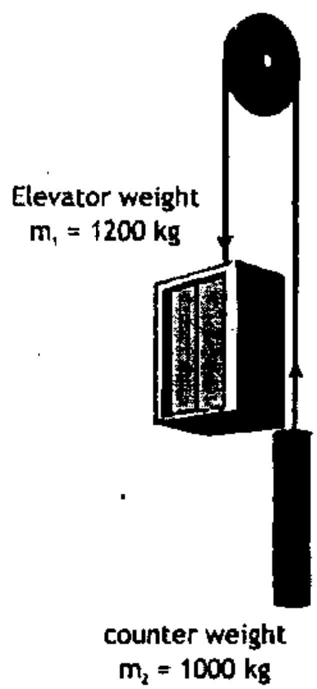
mass of counter weight $m_1 = 1200kg$

mass of elevator $m_2 = 1000kg$

acceleration due to gravity $g = 9.8 m/s^2$

Required: (a) Acceleration a =?

(b) Tension T =?



(a) From Atwood machine equation for acceleration

$$a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g$$

Putting values

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$$a = \frac{1200 - 1000}{1200 + 100} \times 9.8$$

$$a = \frac{200}{2200} \times 9.8$$

$$a = \boxed{0.89\ ms^{-2}}$$

The elevator accelerates downward (and the counterweight upward) at an acceleration of 0.89 m/s^2

(b) From Atwood machine equation for Tension

$$T = \frac{2m_1 m_2}{(m_1 + m_2)} g$$

Putting values

$$T = \frac{2 \times 1200 \times 1000)}{(1200 + 1000)} \times 9.8$$

$$T = \frac{2400000}{2200} \times 9.8$$

$$T = \boxed{10691\ N}$$

The tension in the elevator cable is 10691 N.

EXTENSION EXERCISE 3.3:

Hint: Acceleration will become zero ($m_1 - m_2 = 0$) and Tension in the string will decreases to 9800 N.

ASSIGNMENT 3.8:

SIMPLE ATWOOD MACHINE

Two bodies of mass 3.5 kg and 1.5 kg are tied to ends of string which passes over a pulley. Find the (a) acceleration of bodies and (b) tension in string.

Solution:

Given:

mass $m_1 = 3.5$ kg

mass $m_2 = 1.5$ kg

Required: (a) Acceleration a =?

(b) Tension T =?

(a) From Atwood machine equation for acceleration

$$a = \frac{m_1 - m_2}{m_1 + m_2} g$$

$$a = \frac{3.5 - 1.5}{3.5 + 1.5} \times 9.8$$

$$a = \boxed{3.92 \text{ m/s}^2}$$

(b) From Atwood machine equation for tension

$$T = \frac{2(m_1 m_2)}{m_1 + m_2} g$$

$$T = \frac{2(3.5 \times 1.5)}{3.5 + 1.5} \times 9.8$$

$$T = \boxed{20.58 \text{ N}}$$

EXAMPLE 3.9:

BUG ON DISK

Suppose this bug has a mass m = 5.0 g and sits on the edge of a compact disc of radius 6.0 cm that is spinning such that the bug velocity is 1.2 m/s. Find (a) the centripetal acceleration of the bug and (b) the total force on the bug.

Solution:

Given:

mass m = 5 g = 0.005 kg

Radius of dick r = 6.0 cm = 0.06 m

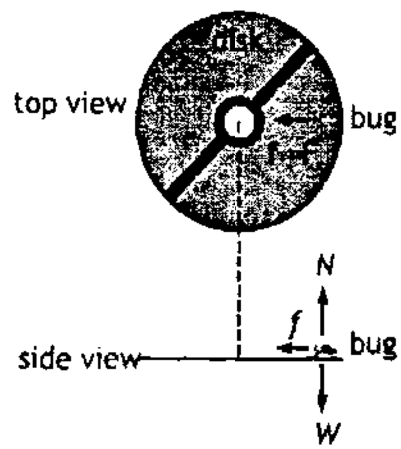
Velocity V = 1.2 m/s^2

Required: (a) Centripetal Acceleration a_c =?

(b) Force on Bug F_c =?

(a) Using the mathematical form of centripetal acceleration

$$a_c = \frac{-v^2}{r}$$



$$a_c = \frac{-(1.2)^2}{0.06}$$

$$a_c = \boxed{-24\ m/s^2}$$

(b) Using the mathematical form of centripetal force.

$$F_c = ma_c$$

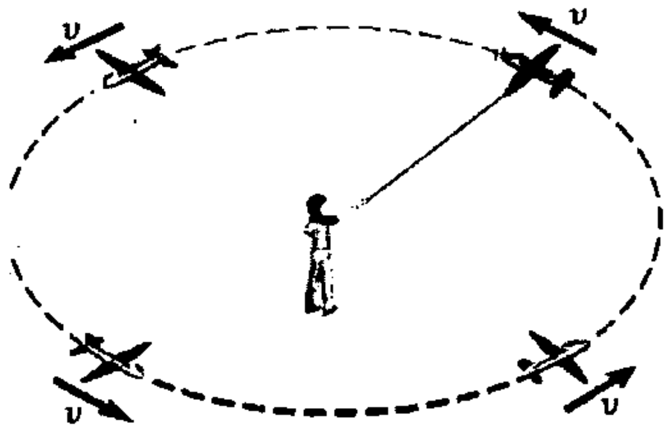
$$F_c = 0.005 \times (-24) = \boxed{-0.12\ N}$$

ASSIGNMENT 3.9:

MASS OF PLANE

A pilot is flying a small plane at 56.6 m/s in a circular path with a radius of 188.5 m. The centripetal force needed to maintain the plane's circular motion is 1.89×10^4 N. What is the plane's mass?

Solution:



Given:

Mass, m = 5 g = 0.005 kg

Radius r = 188.5 m

Centripetal force $F_c = 1.89 \times 10^4$ N

Velocity V = 56.6 m/s^2

Required: Mass of Plane m =?

Using the mathematical formula of centripetal force as

$$F_c = \frac{mv^2}{r}$$

$$m = \frac{F_c \times r}{v^2}$$

$$m = \frac{1.89 \times 10^4 \times 188.5}{(56.6)^2}$$

m = $\boxed{1112.1 \text{ kg}}$

EXERCISE

MULTIPLE CHOICE QUESTIONS

(1) A 30 kg object is supported from rope, such that tension in the rope is equal to its weight. The weight of the object is

A. 30 kg B. 30 N

C. 294 N D. 9.8 N/kg

(2) Force needed to produce an acceleration of 10 m/s^2 in a ball of mass 0.5kg is

A. 20 N B. 10.5 N

C.9.5 N D. 5 N

(3) Ball A collide with ball B which is at rest, after the collision which of the following condition is not possible

A. ball A comes to rest and ball B start moving

B. both balls move in same direction

C. both balls move in opposite directions

D. both balls are at rest

(4) What is mass of a car that is traveling with a velocity of 20 m/s [W] and a momentum of 22000 kg m/s [W]?

A. 440000 kg B. 21980 kg

C. 22020 kg D. 1100 kg

(5) An object at earth is taken to moon should have

A. less mass/less weight

B. same mass/more weight

C. same mass/less weight

D. less mass/same weight

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E. same mass/same weight

(6) The unit of coefficient of friction is

A. N B. Kg

C. μ D. it has no unit

(7) The centripetal acceleration for an object of mass 1kg moving with 6 m/s in a circle of radius 3m is.

A. 18 m/s^2 B. 12 m/s^2

C. 10 m/s^2 D. 2 m/s^2

(8) How many times the centripetal force will increase if the mass of a body moving with uniform speed in a circle is doubled?

A. Six times B. Two times

C. Four times D. Eight times

(9) Which of the following forces can act as a centripetal force?

A. tension B. Friction

C. gravitational force D. All of these

(10) An empty suitcase is placed in the middle of bus on its floor traveling at high speed. When the bus brake suddenly, the suitcase slide

A. backwards B. Forward

C. jumps up D. remains in place

(11) In Newton's third law the action reaction pair does not neutralize each other, because they

A. act on same body B. act on different bodies

C. act on third body D. produce friction

ANSWERS:

1.C	2.D	3.D	4.D	5.C	6.D	7.B	8.B	9.D	10.B	11.B

CONCEPTUAL QUESTIONS

(1) Why does dust fly off, when a hanging carpet is beaten with a stick?

Ans. The dust flies off because of Inertia (or Newton's 1st law of motion)

Explanation:

The dust that is stuck with the carpet is initially at rest. When you beat up the carpet, it suddenly starts motion but the dust wants to be in rest due to which it flies off from the carpet.

(2) If your hands are wet and no towel is handy, you can remove some of the excess water by shaking them. Why does this work?

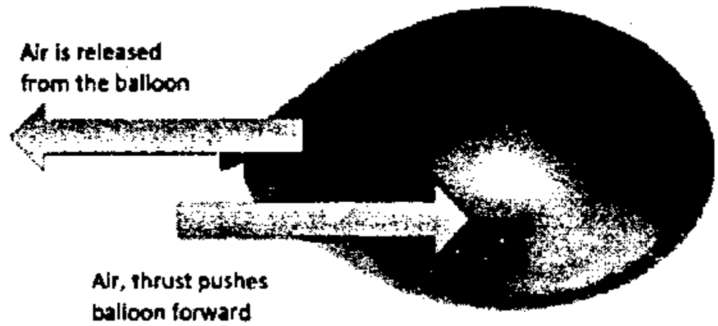
Ans. Water removes from your hands because of inertia.

Explanation:

When you shake up your hands that are wet, the water attached to hands removes. It is because the water wants to remain in rest while your hands start motion due to which excess water removes from your hand. Same principle is involved when you shake up wet clothes quickly; water drops fly off from it.

(3) Why a balloon filled with air move forward, when its air is released?

Ans. It is because of the reaction force that a balloon filled with air move forward or upward when its air is released.



Explanation:

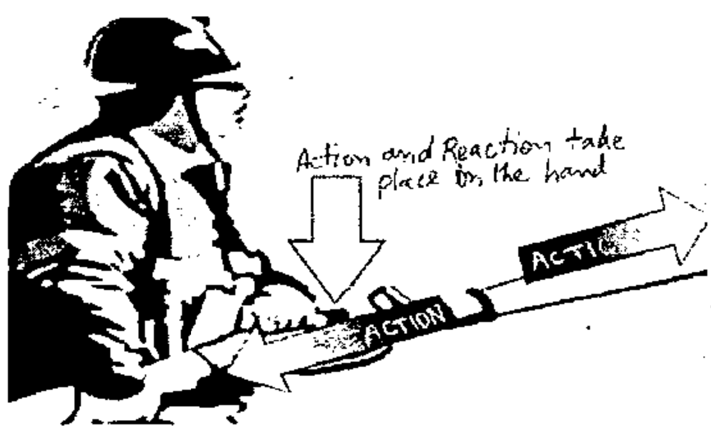
As shown in the diagram, when the air is released towards left by the balloon, the balloon itself moves towards right as a reaction. Here Newton's 3rd law of motion (For every action there is an equal but opposite reaction) is involved.

Mathematically

$F_{action} = -F_{reaction}$

(4) Why does a hose pipe tend to move, backward when the fireman directs a powerful stream of water towards fire?

Ans. It is because of reaction force that a hose pipe tends to move backward when the fireman directs a powerful stream of water towards fire.



Explanation:

As shown in the diagram a firefighter holds a hose pipe in his hands. As he turns on the water, he feels a backward force. This force (backward) is a reaction to the force on water stream (forward)

Mathematically,

$F_{action} = -F_{reaction}$

(5) Your car is stuck in wet mud. Some students on their way to class see your predicament and help out by sitting on the trunk of your car to increase its traction. Why does this help?

Ans. It increases the normal force (weight) of the car which increases frictional force. This causes the tires more sticky to the wet mud which helps the car out of the mud.

Explanation:

When the car is stuck in the wet mud and students set on its trunk it actually increases weight of the car which in turn increases normal force. Increase in normal force increases friction of car tyres by relation

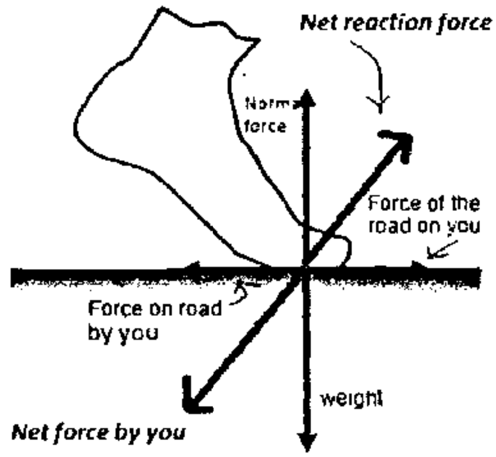
$f_s \propto F_N$

(6) How does friction help you walk? Is it kinetic friction or static friction?

Ans. The friction sticks your foot on ground instead of going back by your force that you applied to move on ground.

Explanation:

As shown in the figure when you push the ground with a force (sum of your weight and the pushing force) as a reaction ground pushes you with same force. If friction was not present then instead of forward walking you would go backward or even slipping.

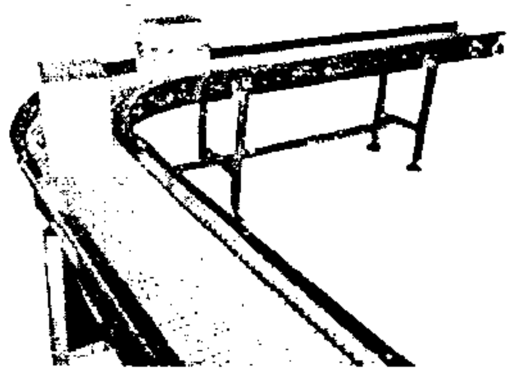


(7) The parking brake (hand brake) on a car causes the rear wheels to lock up. What would be the likely consequence of applying the parking brake in a car that is in rapid motion?

Ans. As the rear wheel of the car locks as shown in the figure then it will rotate at its position instead of moving forward. The likely consequences will be that the car will go out of control of the driver and can cause a major accident. It is very dangerous and should not be exercise by you or you are near and dear.

(8) Why is the surface of a conveyor belt made rough?

Ans. It is done so as to increase the friction of the conveyor built to avoid slipping of baggage carried upon it from one place to another.

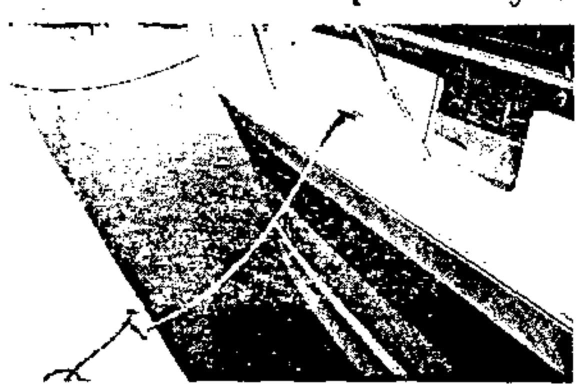


Explanation:

To decrease the slipping property of the built normally its upper surface is made rough and zigzag. By doing so it becomes easy to carry baggage through it.

(9) Why does a boatman tie his boat to a pillar before allowing the passengers to step on the river bank?

Ans. It is to stop the motion of boat as on water surface the frictional force is comparatively low.

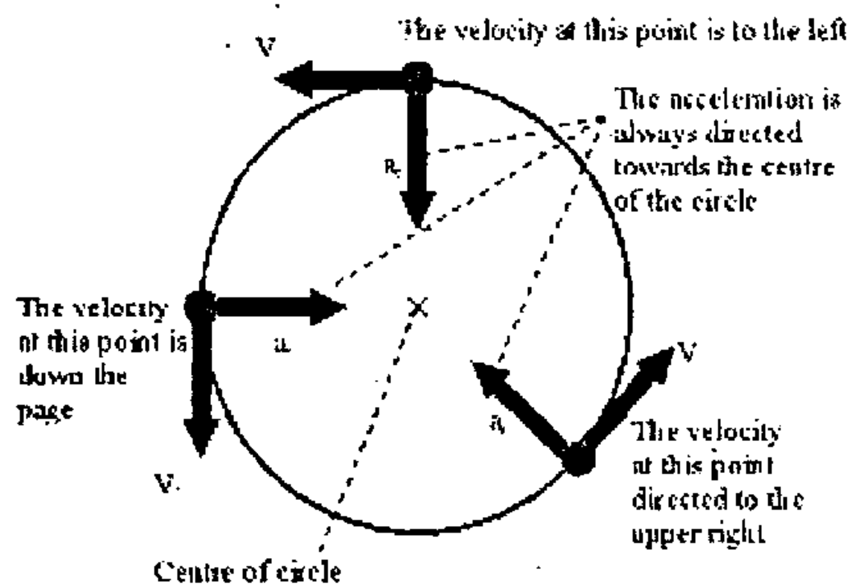


Explanation:

When the boat comes to the shore and passengers want to land from it, the boatman first ties the boat to a pillar (called dock) as shown in the figure. If the boatman doesn't do it, the boat will slip on water surface and will move away from the shore.

(10) In uniform circular motion, is the velocity constant? Is the acceleration constant? Explain.

Ans. In uniform circular motion the magnitude of velocity is constant but its direction continuously changes which causes acceleration (called centripetal acceleration) to produce in the body. This acceleration is constant in case of uniform circular motion as shown in the figure.



Explanation:

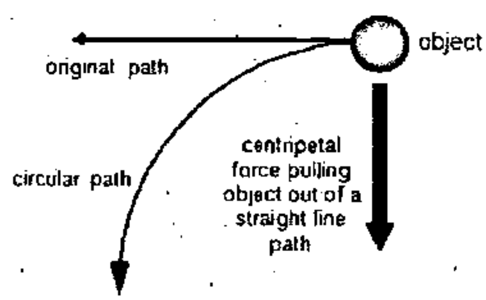
In uniform circular motion the magnitude of velocity remains constant at every point of the circle. Only its direction always changes because of the

centripetal force which is always directed towards the centre. This centripetal force produces centripetal acceleration in the body which is also directed towards the centre. This acceleration remains constant as long as the magnitude of velocity and radius of the circle remains constant which is a pre-condition for uniform circular motion.

(11) You tie a brick to the end of a rope and whirl the brick around you in a horizontal circle. Describe the path of the brick after you suddenly let go of the rope.

Ans. The brick will go out of the circle because the centrifugal force seizes and the brick will start motion in the direction of tangential velocity.

Explanation:



Tension in the rope (due to your hand force) provides the necessary centripetal force to keep the move in circular path (circular motion). As you leave the rope, the tension in the rope diminishes causes centripetal force (that is necessary for circular motion) to end at the same time. And you will see the brick along with the rope will move away from you as shown in the figure.

(12) Why is the posted speed for a turn lower than the speed limit on most highways?

Ans. The maximum speed limit for a turn is lower than normal because is that case the frictional force will

not be sufficient to provide necessary centripetal force.

Explanation:

Increasing the speed from a certain value is prohibited in a turn. As you reaches the posted speed the centripetal force not sufficient for the car to turn. The car will skid away from the road causes accidents.

NUMERICAL PROBLEMS

(1) 1580-kg car is traveling with a speed of 15.0 m/s. What is the magnitude of the horizontal net force that is required to bring the car to a halt in a distance of 50.0 m?

Solution:

Given:

Mass of car m = 1580 kg

Initial velocity of car v_i = 15.0 m/s

Final velocity of car v_f = 0m/s (As the car finally stops)

Distance s = 50.0 m

Required: Net Force F =?

Using mathematical form of Newton's 2nd law of motion

$F = ma$

Putting $a = (v_f^2 - v_i^2) / 2s$ in above equation

$$F = \frac{m(v_f^2 - v_i^2)}{2s}$$

Putting values

$$F = \frac{1580(0^2 - 15^2)}{2 \times 50}$$

$F = 3550\ N = \boxed{3.55 \times 10^3\ N}$

(2) A bullet of mass 10 g is fired with a rifle. The bullet takes 0.003 s to move through barrel and leaves with a velocity of 300 m/s. What is the force exerted on the bullet by the rifle?

Solution:

Given:

Mass of bullet m = 10 g = 0.01 kg

Initial velocity of bullet $v_i = 0$ m/s

Final velocity of bullet $v_f = 300$ m/s

Time t = 0.003 s

Required: Net Force F =?

Using mathematical form of Newton's 2nd law and 1st equation of motion

$$F = \frac{m(v_f - v_i)}{t}$$

Putting values

$$F = \frac{0.01(300-0)}{0.003}$$

$F = 1{,}000\ N = \boxed{1.0 \times 10^3\ N}$

Method# 2:

It can also be solved using Formula $F = \frac{\Delta p}{\Delta t}$

(3) A 2200-kg vehicle traveling at 94 km/h (26 m/s) can be stopped in 21s by gently applying the brakes. It can be stopped in 3.8s if the driver slams on the brakes. What average force is exerted on the vehicle in both of these stops?

Solution:

Given:

Mass of vehicle m = 2200 kg

Initial velocity of vehicle v_i = 94 km/h = 26 m/s

Final velocity of vehicle v_f = 0 m/s (As the vehicle finally stops)

Time to stop vehicle gently t_1 = 21 s

Time to stop vehicle abruptly t_2 = 3.8 s

Required: Force to stop gently F_1 =?

Force to stop abruptly F_2 =?

Using Newton's 2nd law of motion and 1st equation of motion

$$F_1 = \frac{m(v_f - v_i)}{t_1}$$

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Putting values

$$F_1 = \frac{2200(0-26)}{21}$$

$F_1 = 2723.8\text{ N} = \boxed{2.7\times10^3\text{ N}}$

Similarly, for stopping the car gently. Using Newton's 2nd law of motion and 1st equation of motion.

$$F_2 = \frac{m(v_f - v_i)}{t_2}$$

Putting values

$$F_2 = \frac{2200(0-26)}{3.8}$$

$F_2 = 15052.63\text{ N}$

$F_2 = \boxed{1.5\times10^4\text{ N}}$

(4) You want to move a 500-N crate across a level floor. To start the crate moving, you have to pull with a 230-N horizontal force. Once the crate "breaks loose" and starts to move, you can keep it moving at constant velocity with only 200 N. What are the coefficients of static and kinetic friction?

Solution:

Given:

Weight of crate $W = F_N = 500\text{ N}$

Static friction $f_s = 230\text{ N}$

Kinetic friction $f_k = 200\text{ N}$

Required: Coefficient of static friction μ_s =?

Coefficient of kinetic friction μ_k =?

Static friction is defined by the mathematical formula as

$$f_s = \mu_s F_N$$

$$\mu_s = \frac{f_s}{F_N}$$

$$\mu_s = \frac{230}{500}$$

$$\mu_s = \boxed{0.46}$$

Kinetic friction is defined by the mathematical formula

$$f_k = \mu_k F_N$$

$$\mu_k = \frac{f_k}{F_N}$$

$$\mu_k = \frac{200}{500} = \boxed{0.4}$$

(5) Two bodies of masses 3 kg and 5 kg are tied to string which is passed over a pulley. If the pulley has no friction, find the acceleration of the bodies and tension in the string.

Solution:

Given:

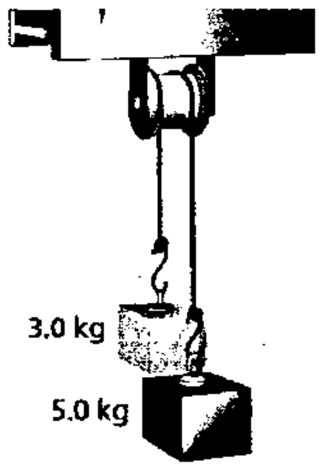
Mass $m_1 = 5$ kg

Mass $m_2 = 3$ kg

Required: Acceleration a =?

Tension T =?

Using mathematical formula of acceleration



$$a = \frac{(m_1 - m_2)}{(m_1 + m_2)} \times g$$

$$a = \frac{(5-3)}{(5+3)} \times 9.8$$

$$a = \boxed{2.45\ m/s^2}$$

Using mathematical formula of Tension

$$T = \frac{(2m_1 m_2)}{(m_1 + m_2)} \times g$$

$$T = \frac{(2 \times 5 \times 3)}{(5+3)} \times 9.8$$

$$T = \boxed{36.75\ N}$$

(6) Determine the magnitude of the centripetal force exerted by the rim of a car's wheel on a 45.0-kg tire. The tire has a 0.480-m radius and is rotating at a speed of 30.0 m/s.

Solution:

Given:

Mass of tire m = 45.0 kg

Radius of tire r = 0.480 m

Velocity of tire V = 30.0 m/s

Required: Centripetal Force F_c =?

Using mathematical formula of centripetal force

$$F = \frac{mv^2}{r}$$

$$F_c = \frac{45 \times 30^2}{0.480}$$

$$F_c = \frac{40,500}{0.480}$$

$$F_c = 84,375\ \text{N} = \boxed{8.44 \times 10^1\ \text{N}}$$

(7) A motorcyclist is moving along a circular wooden track of a circus (death well) of radius 5 m at a speed of 10 m/s. If the total mass of motorcycle and the rider is 150 kg find the magnitude of the centripetal force acting on him?

Solution:

Given:

Radius of circle $r = 5$ m

Speed of motorcycle $V = 10$ m/s

Mass of motorcycle + Rider = 150 kg

Required: Centripetal Force F_c =?

Using mathematical formula of centripetal force

$$F_c = \frac{mv^2}{r}$$

$$F_c = \frac{150 \times 10^2}{5} = \frac{15000}{5}$$

$$F_c = 3,000\ \text{N} = \boxed{3 \times 10^3\ \text{N}}$$

(8) A car of mass 1000 kg is running on a circular motor way interchange near Swabi with a velocity of 80 m/s the radius of the circular motor way inter change is 800 m. How much centripetal force is required?

Solution:

Given:

Mass of car m = 1000 kg

Velocity of car = 80 m/s

Radius of circle r = 800 m

Required: Centripetal Force F_c =?

Using mathematical formula of centripetal force

$$F_c = \frac{mv^2}{r}$$

$$F_c = \frac{1000 \times 80^2}{800} = \frac{6,400,000}{800}$$

$$F_C = 8,000 \text{ N} = \boxed{8 \times 10^3 \text{ N}}$$

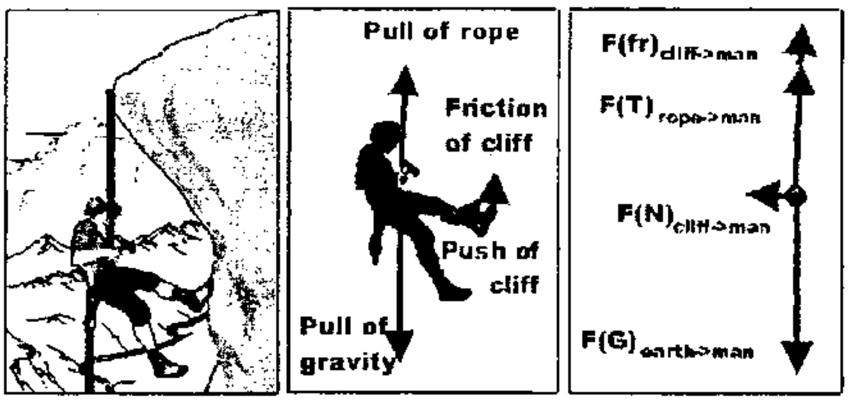
--❀❀❀--

Unit 4

Turning Effect of Forces

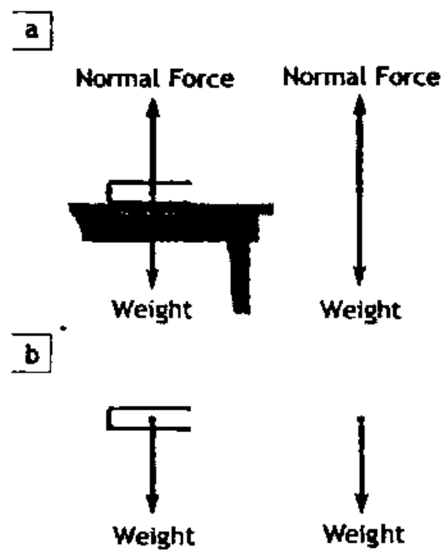
Q.1: What are force diagrams? Define like and unlike parallel forces with example.

Ans. *To study the effects of forces acting on any object, we can apply the skill of drawing force diagrams.* Since force is a vector quantity it can be represented by an arrow.



Explanation:

Force diagrams are very useful conceptual tools because they help examine the forces acting on an object.



For example, if we were to draw a force diagram of this textbook placed at rest on table, we would reduce textbook to a dot, and draw two arrows representing forces acting on it, as shown in figure 4.1a.

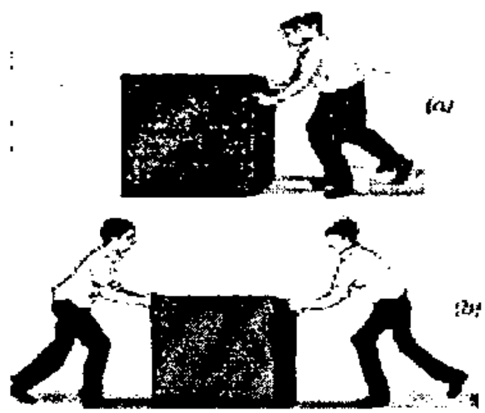
One of the forces is the

weight the book, pulling it downward. The other force is the normal force due to the table pushing the book upward. These forces are equal and opposite; that is, the magnitude of the gravitational force is equal to the magnitude of the upward force due to the table. These two forces are an example of balanced forces. When an object is acted on by balanced forces, the forces cancel out each other out and the object behaves as though no force is acting on it.

Like and unlike parallel forces:

"If the directions of forces are parallel to each other, even if they are in opposite direction, then such forces are known as parallel forces".

When the parallel forces are in the same direction then they are called like parallel forces as shown in figure (a). When the parallel forces are in opposite direction then they are called unlike parallel forces.

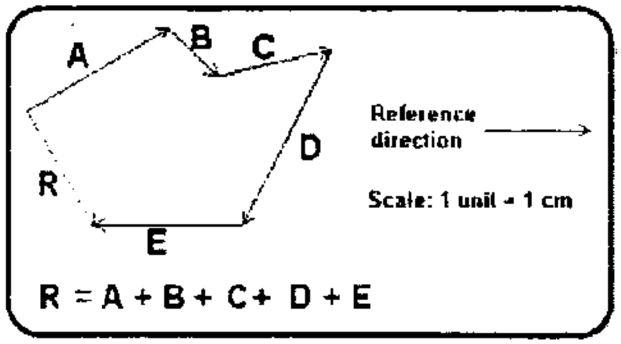


Q.2: Explain the addition of forces, in connection with head to tail rule.

Ans. **Addition of vectors:**

Vectors cannot be added like scalars but are added through head to tail rule which is as follow:

Draw first vector (A) in the given direction, start tail of the second vector (B) from the head of first vector, start tail of the third vector (C) from the head of second vector and so on. Finally draw the resultant (R) starting from the tail of first vector towards the head of last vector as shown in the diagram. A proper scale is used to represent higher magnitudes of vectors in the diagram.

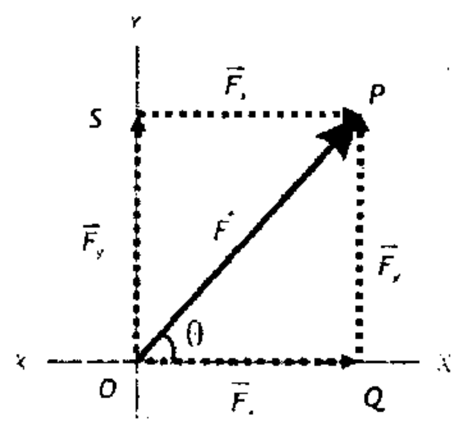


For example, we have given 1st vector of magnitude 15 km, then we can use a scale such that 5 km = 1 cm.

Q.3: What is resolution of forces? Explain with an example how forces can be resolved into rectangular components.

Ans. **Resolution of vectors:**

The process of splitting a force vector into two or more force vectors is called resolution of forces. The force vectors so obtained are called components.



Resolution of forces is opposite to the addition in which we get one vector by adding several vectors. If components obtained from this process are perpendicular

to each other, they are called rectangular components of a vector as shown in the figure. Resolving forces into rectangular components help us to analytically add forces rather than needing a ruler or protector.

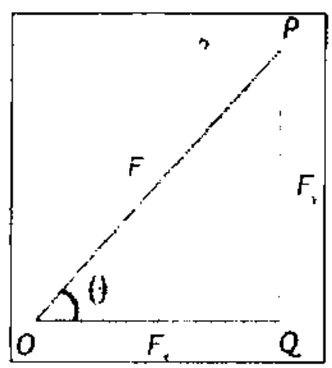
Consider a force F in the Cartesian coordinate system, represented by the line OP, making an angle θ as shown in the figure. Draw perpendiculars from point P on x-axis and y-axis which meets the axis at points Q and S respectively. Put arrow head from the direction of O towards Q and S such that they represent vectors as $\vec{F}_x$ (OQ & SP) and $\vec{F}_y$ (OS & QP), becomes the rectangular components of vector $\vec{F}$ (OP)

By head to tail rule of vector addition, we know that force $\vec{F}$ is the vector sum of $\vec{F}_x$ and $\vec{F}_y$, mathematically

$$\vec{F} = \vec{F}_x + \vec{F}_y$$

Rectangular components are given by

$$cos\theta = \frac{base}{hyp} = \frac{OQ}{OP} \text{ or } cos\theta = \frac{F_x}{F}$$



Therefore,

$$F_x = F\,cos\theta \text{ .... } 1$$

Similarly,

$$sin\theta = \frac{perp}{hyp} = \frac{QP}{OP} \text{ or } sin\theta = \frac{F_y}{F}$$

Therefore,

$$F_y = F\,sin\theta \text{ .... } 2$$

This means that we can calculate the components analytically just by knowing the value of force and the angle.

Force in terms of rectangular components:

Since triangle ΔOPQ, from a right-angle triangle, therefore we can use Pythagoras theorem, which states that

$$(hyp)^2 = (base)^2 + (perp)^2$$

$$\sqrt{hyp^2} = \sqrt{base^2 + perp^2}$$

$$\text{hyp} = \sqrt{base^2 + perp^2}$$

$$\text{or OP} = \sqrt{(OQ)^2 + (QP)^2}$$

$$\text{Therefore, F} = \sqrt{F_x{}^2 + F_y{}^2} \text{ .... 3}$$

The magnitude of vector can now be determined if the values of the magnitudes of components are known.

To determine the direction in right angle triangle ΔOPQ, we have tan θ as

$$tan\theta = \frac{perp}{base} = \frac{QP}{OQ}$$

$$\text{Or } tan\theta = \frac{F_y}{F_x}$$

$$\text{Therefore, } \theta = tan^{-1}\theta\frac{F_y}{F_x} \text{ .... 4}$$

Q.4: Define moment of a force. Give its mathematical description and elaborate the factors on which it depends?

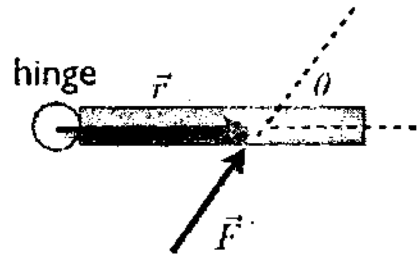
Ans. Moment of Force (Torque):

Turning effect produced in a body about a fixed point due to applied force is called torque or moment of force.

Mathematically

$\tau = \vec{F} \times \vec{r}$ ...... (1)

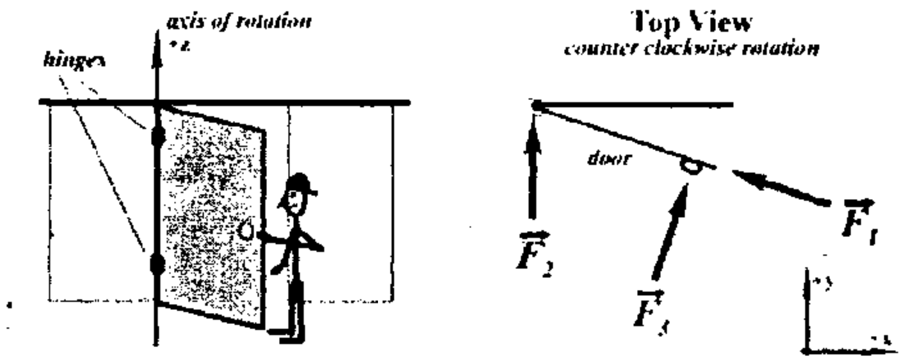
$\tau = Fr\sin\theta\,\hat{n}$...... (2)



Whereas, "$Fr\sin\theta$" is magnitude of torque and $\hat{n}$ is direction of torque (Normal to both $\vec{F}$ and $\vec{r}$).

Explanation:

Force can be used to produce rotation in an object, for example in opening a door or tightening a nut with spanner or wrench as shown in the figure.



$\vec{F}_1$ and $\vec{F}_2$ will not produce rotation

Torque is the cause of changes in rotational motion and is similar to force, which causes changes in translational motion. This means that torque plays the same role in rotation as force in translation.

Mathematical description:

Magnitude of torque from equation (2) is given by

$\tau = Fr\sin\theta$

From the above equation

(a) If force and moment arm are parallel to each other (Force F_1 in the above diagram) then no torque will be produced. Mathematically

$\tau = Fr \sin 0^0 = Fr \sin 180^0$

From the given table put value of $\sin 0^0 = 0$ or $\sin 180^0 = 0$

$\tau_{min} = 0$

θ	sin θ	cos θ	tan θ
0°	0.000	1.000	0.000
30°	0.866	0.500	0.577
45°	0.707	0.707	1.000
60°	0.866	0.500	1.732
90°	1.000	0.000	infinite

(b) If force and moment arm are perpendicular to each other (Force F_3 in the above diagram) then maximum torque will be produced. Mathematically

$\tau = Fr \sin 90^0$

From the given table put value of $\sin 90^0 = 1$

$\tau_{max} = F_3 r$

(c) If force is acting exactly on the hinges (Force F_2 in above figure) then the torque will be equal to zero as then moment arm diminishes. Mathematically

$\tau = Fr \sin\theta$

$\tau = F\,(0)\ \sin\theta$

$\tau_{min} = 0$

Direction of torque ($\hat{n}$):

Direction can be found by right hand rule and have only two types clockwise (If the force is capable of rotating the body in clockwise direction, the torque is known as clockwise torque) and anti-clockwise (If the force is capable of producing rotation in the anti-

clockwise direction, the torque is known as anti-clockwise torque.)

It also depends upon view point. If a direction viewed from above is clockwise the viewing it from below will be anti-clockwise. Conventionally, clockwise torque is taken as negative, whereas anticlockwise torque is taken as positive.

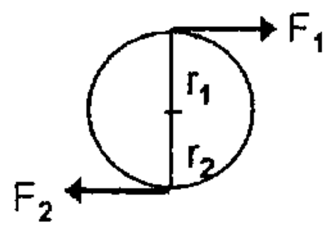
Factors affecting torque:

Torque is affected by the following three factors.

(a) The applied force F. Increasing force increases torque i.e. torque is directly proportional to the applied force. Mathematically, $\tau \propto F$

(b) The moment arm r increasing moment arm increases torque i.e. torque is directly proportional to the moment arm. Mathematically, $\tau \propto r$

(c) The angle between force and moment arm θ. Torque is maximum when F and r are perpendicular to each other (as in case of F_3 I above diagram) while minimum when they are parallel to each other (as in case of F_1 in above diagram).



Q.5: What is couple? Explain with examples.

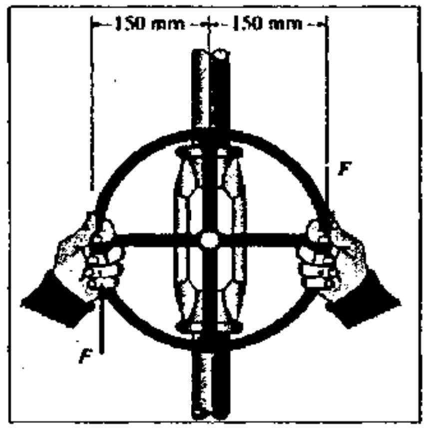
Ans. *Two equal and opposite parallel forces acting along different lines on a body constitute a couple as shown in the figure.*

Explanation:

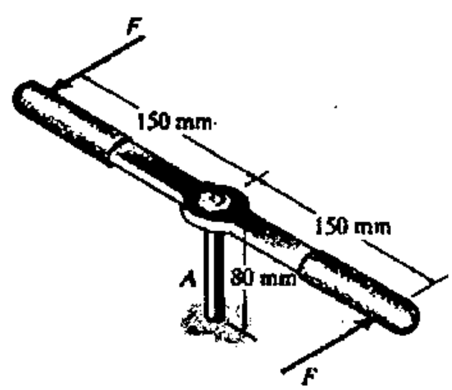
In the given diagram two forces ($\vec{F}_1$ and $\vec{F}_2$) are shown directed opposite to each other (one pointing upward and other downward). Such forces are called as couple forces.

The resultant force of a couple is zero but the resultant of a couple is not zero; it is a pure moment (causes torque to produce) The shortest distance between two couple forces is called *couple arm.*

For example, a driver turns the steering of a car as shown in the figure. The driver exerts two forces opposite to each other along different lines of action makes a couple. Similarly, when you are tightening or losing a nut bolt by a wheel spanner as shown in the figure.



Two forces are acting oppositely directed, makes a couple. Here the resultant force is zero as both are equal in magnitude and oppositely directed. Yet, the resultant effect (called moment of force or torque) is not zero.



Q.6: Define equilibrium. Explain its types and state the two conditions of equilibrium.

Ans. <u>**Equilibrium:**</u>

Equilibrium is that state of body in which under the action of several forces acting together, there is no change

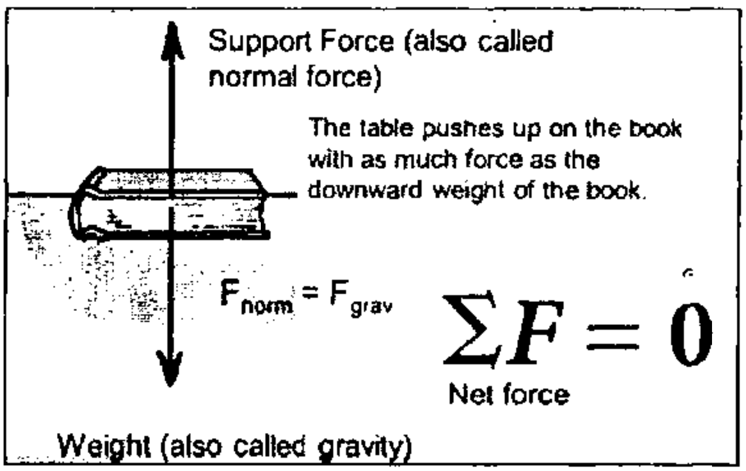
in translational as well as in rotational motion is called equilibrium.

Explanation:

The two types of acceleration are mentioned here. Translational acceleration (because of the non-zero resultant force) and rotational acceleration (because of non-zero resultant torque)

Types of equilibrium:

There are basically following two types of equilibrium.



(A) Static equilibrium:

The type of equilibrium in which there is no motion at all and the body remains at rest under the action of several forces.

For example, a book lying on a table is at rest under the force of gravity (downward) and normal force exerted by the table (upward) as shown in the diagram. There is no change in velocity of the body and hence no acceleration is produced. It is only possible if all the forces acting on the body results to zero.

(B) Dynamic equilibrium:

The type of equilibrium in which the body in uniform translational or circular motion i.e. there is no translational or rotational acceleration in the body.

It is further divided into two types called dynamic translational equilibrium (possible only when $\vec{F}_{net}=0$) and dynamic rotational equilibrium (possible only when $\tau_{net}=0$)

Conditions of Equilibrium:

There are two conditions for complete equilibrium. Both are necessary but not (independently) sufficient for complete equilibrium.

A. First Condition of Equilibrium:

When the vector sum of all the forces acting on the body is ZERO then the first condition of equilibrium is satisfied.

Mathematically if F_{net} is the sum of forces F_1, F_2, F_3, ..., F_n then

$$\vec{F}_{net}=\vec{F}_1+\vec{F}_2+\vec{F}_3+.......+\vec{F}_n=0$$

$$\vec{F}=\sum_{i=1}^{i=n}F_i=0$$

B. Second Condition of equilibrium:

When the vector sum of all the Torques acting on the body is ZERO then the second condition of equilibrium is satisfied. If $\vec{\tau}_{net}$ is the sum of torques $\vec{\tau}_1,\vec{\tau}_2,\vec{\tau}_3..........\vec{\tau}_n$ then mathematically

$$\overrightarrow{\tau_{net}}=\sum_{i=1}^{i=n}\overrightarrow{\tau_i}=0$$

Q.7: State and explain principle of moments with examples.

Ans. **Principle of moments:**

"When an object is in equilibrium, the sum of clockwise moments (called torque) about a turning point must be equal to the sum of anti-clockwise moments."

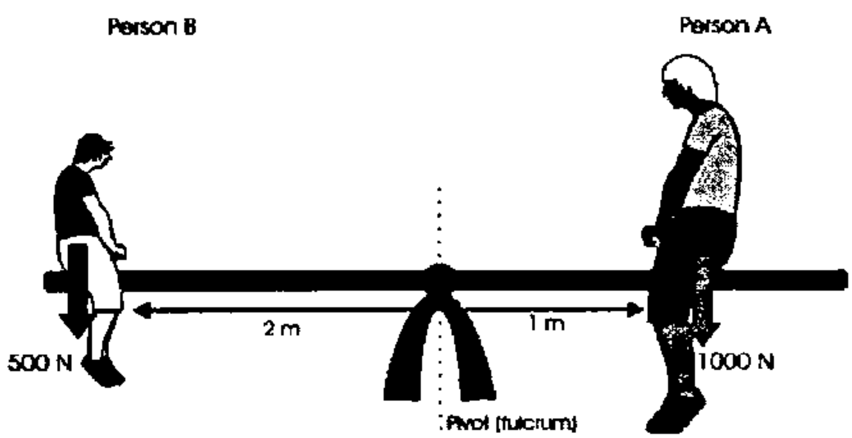
Mathematically,

Sum of clockwise moments= sum of anti-clockwise moments

$$\sum \vec{\tau}_{clock} = \sum \vec{\tau}_{anticlock}$$

$$\sum (\vec{r} \times \vec{F})_{clock} = \sum (\vec{r} \times \vec{F})_{anticlock}$$

In other words, we can say that second condition of equilibrium is actually principle of moments.



As shown in the diagram, two persons (of weights 1000N and 500N) are setting on a plane placed on a fulcrum (pivot) Different weights and different moment arms (1m and 2m respectively) still the system is in equilibrium because clockwise moment (produced by person A) is equal to anti-clockwise moment (produced by person B).

Mathematically

$$\sum(\vec{r}\times\vec{F})_{clock}=\sum(\vec{r}\times\vec{F})_{anticlock}$$

Putting values from the diagram

$$1m\times1000N=2m\times500N$$

1000Nm (clockwise)= 1000Nm (anti-clockwise)

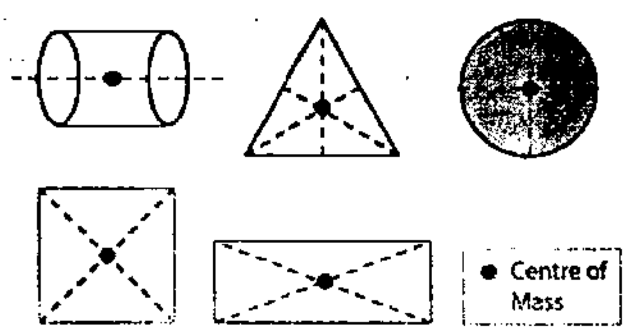
Similarly, if we have more than two moments, the same principle will be applied. Sum of all clockwise moments will be equal to sum of all anti-clockwise moments.

Q.8: What is centre of mass or centre of gravity? Explain how CM/CG can be determined? Is there any difference between CM and CG?

Ans. **Centre of mass and centre of gravity:**

The centre of mass of a body is the point about which its mass is equally distributed in all direction as shown in the figure.

Whereas the point where whole weight of the body appears to act is called centre of gravity.



Explanation:

The centre of mass is the point at which we can imagine all the mass of an object to be concentrated.

Thus, the centre of mass is also the point at which we can imagine the force of gravity on the entire object to be acting. If we can imagine all of the mass to be concentrated at this point when calculating the force due to gravity, it is legitimate to call this point the centre of gravity, a term that can often be used interchangeably with centre of mass.

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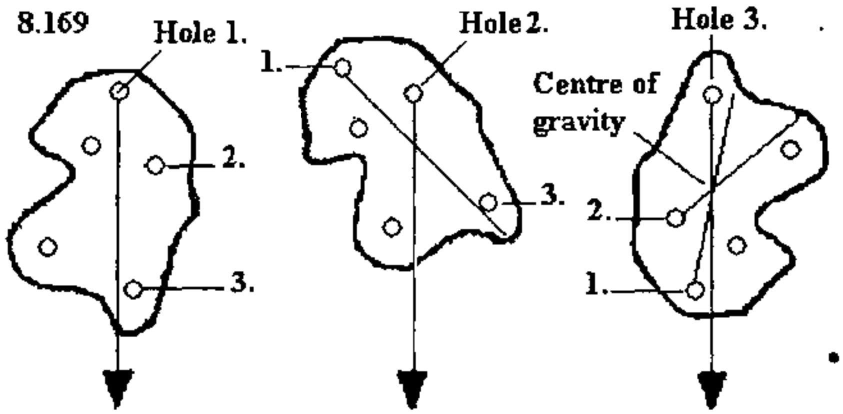
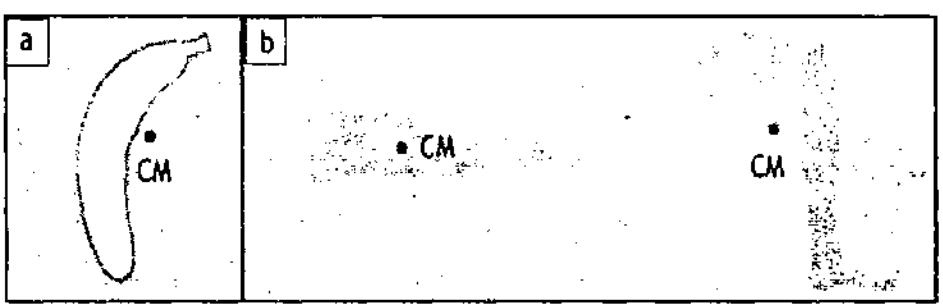


It is not necessary that centre of mass should always be inside the body. It can be outside as shown in the figure.

Determination:

For symmetric bodies the centre of mass or centre of gravity is its geometric centre as shown in above figure. For non-symmetric (irregular) bodies we usually suspend it from different points and draw line through it with freely suspending bodies as shown in the figure.



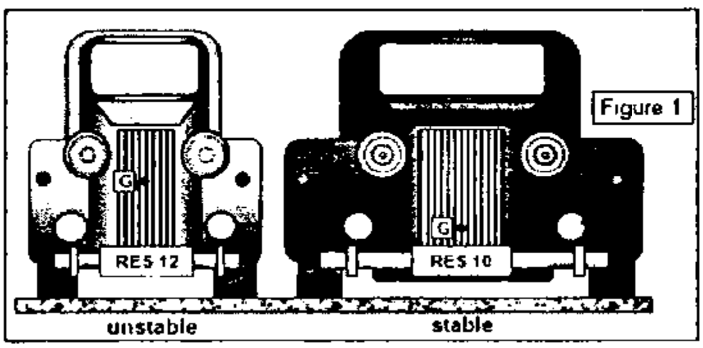
Difference between centre of mass and centre of gravity:

The acceleration due to gravity decreases with altitude; but for small objects this variation is negligible, the body's centre of gravity is for most of the time same as its centre of mass.

Q.9: Explain the stability of the objects with reference to position of centre of mass.

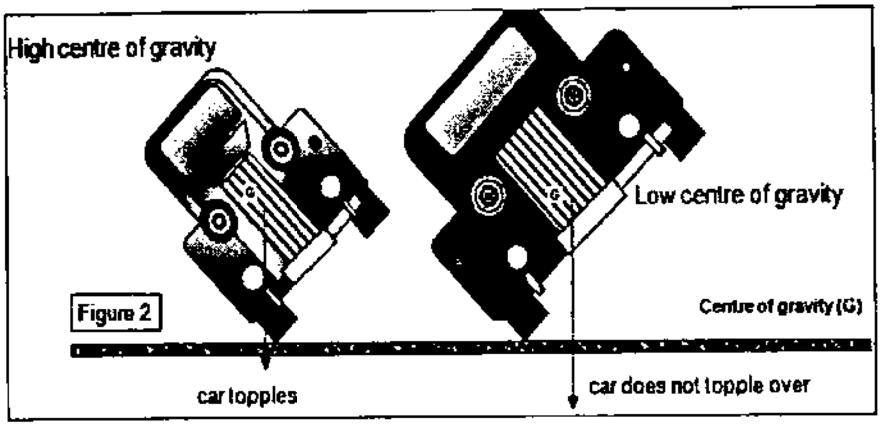
Ans. Stability:

The measure of how hard it is to disturb the equilibrium state of a body is called stability. OR The stability of an object refers to the ability of the object to return to its original position when the force that changed its orientation is removed.



Explanation:

The conditions of equilibrium do not specify whether an object is stable or not. The stable object does not topple easily. The position of the centre of mass of a body affects whether or not it topples over easily. This is important in the design of such things as tall vehicles (which tend to overturn when rounding a corner), racing cars, reading lamps and even drinking glasses.



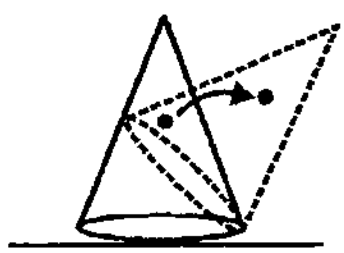
Note:

Increasing the area of the base will also increase the stability of an object, the bigger the area the more stable the object as shown in figure 1.

If centre of gravity of an object is more near to earth, more stable the object will be than objects of same size having centre of gravity away from earth as shown in the figure 2.

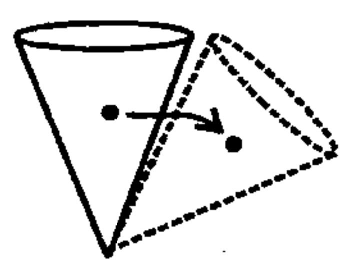
On the basis of stability, equilibrium has been divided into the following types.

1. **Stable equilibrium:**



When force acting on a body raises centre of gravity of the body then after the release of force, the body come back to its original position. This type of equilibrium is called stable equilibrium. For example, a cone lying on the table with it wider side.

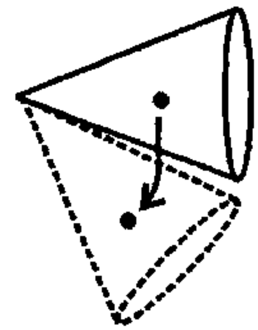
2. **Unstable equilibrium:**



When a force acting on a body is released but the body does not come back to its original position, then this type of equilibrium is called unstable equilibrium. It is because, that when

the force is applied it lawers the c.g. For example, a cone balanced on its tip when disturbed.

3. **Neutral equilibrium:**



When force acting on a body does not change centre of gravity of a body, then it is said to be in neutral equilibrium. For example, cone lying on the table in horizontal direction.

Examples and Assignments:

EXAMPLE 4.1

PULLING TRASH IN DIFFERENT DIRECTIONS

Two people, A and B, are pulling a trash cart with two ropes. Person A applies a force 20 N [50^0 with x-axis] on one rope. Person B applies a force of 15 N [0^0 with x-axis] on the other rope. Calculate the magnitude of net force on the trash cart.

Solution:

Given:

$\theta_A = 50^0$ with x-axis

$\theta_B = 0^0$ with x-axis

Required: Net force $\vec{F}_{net} = ?$

Scale:

Let 5 N = 1 cm

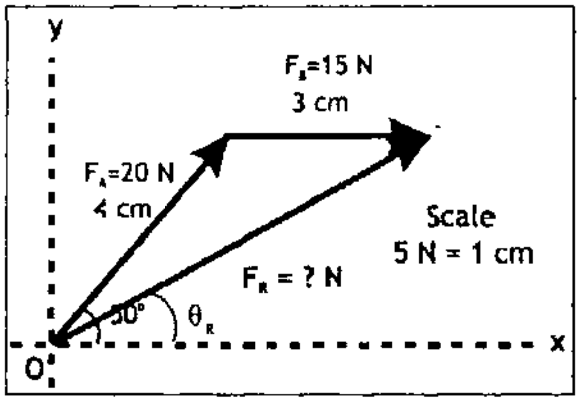
Then 15 N = 3 cm

And 20 N = 4 cm

We joined the tail of the first to the head of the second vector to get the resultant F_{net}. We then measured

the length of vector F_R which was about 6.2cm ($6.2\times5 = 31N$), and with the protector we calculated the value of angle $\theta = 30^0$ with x-axis.

$$\boxed{\vec{F}_{net} = 31N \text{ (30° with x-axis)}}$$



Extension 4.1 Hint: No, it does not make any difference.

ASSIGNMENT 4.1:

HEAD TO TAIL RULE

Two forces are applied one force is 25N [20^0 with x-axis] and the other force is 10N [$60^0$with x-axis], find the net resultant force.

Solution:

Given:

$\theta_A = 60^0$ with x-axis

$\theta_B = 20^0$ with x-axis

Required: Net force $\vec{F}_{net} = ?$

Scale:

Let 5N = 1cm

Then 10N = 2cm

And 25N = 5cm

We joined the tail of the first to the head of the second vector to get the resultant F_{net}. We then measured the length of vector F_R which was about 6.6cm (6.6×5=33N), and with the protector we calculated the value of angle $\theta = 30.1^0$ with x-axis.

$$\boxed{\overline{F}_{net} = 33N \ \ (30.1^0 \text{with x-axis})}$$

EXAMPLE 4.2

PULLING A BOX ON FLOOR

Divia is pulling a box on the floor with a force of 20N making an angle of 60⁰ with the horizontal. Find the horizontal and vertical components of this force.

Solution:

Given:

Force F = 20N

Angle $\theta = 60^0$ with horizontal

Required: (a) Horizontal component F_x =?

(b) Vertical component F_y =?

(a) The horizontal component is given by

$F_x = F\cos\theta$

Putting values

$F_x = 20\cos 60^0$

As cos60 = 0.5,

$F_x = 20 \times 0.5 = \boxed{10N}$

(b) The vertical component is given by

$F_y = F\sin\theta$

Putting values

$F_y = 20\sin 60$

As sin60 = 0.866

$F_y = 20 \times 0.866 = \boxed{17.3N}$

ASSIGNMENT 4.2:

TILLING GARDEN

While tilling your garden, you exert a force on the handles of the tiller that has components F_x=85N and F_y = 13N. The x-axis is horizontal and the y-axis points up. What are the magnitude and direction of this force?

Solution:

Given:

Horizontal component of force F_x = 85N

Vertical component of force F_y = 13 N

Required: Net force $\vec{F}_{net} = ?$

First, we will find magnitude of resultant force that is given by

$F = \sqrt{F_x^2 + F_y^2}$

Putting values

$F = \sqrt{(85)^2 + (13)^2} = \sqrt{7225 + 169} = \sqrt{7394}$

$\boxed{F = 86\ N}$

Now finding direction of net force

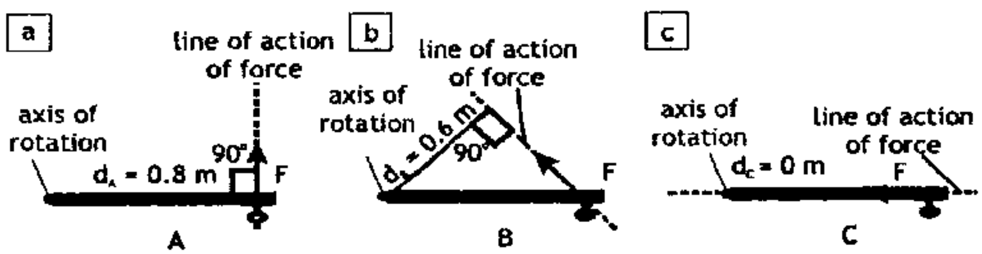
$$\theta = tan^{-1}\frac{F_y}{F_x} = tan^{-1}\frac{13}{85} = tan^{-1}0.1529$$

$$\boxed{\theta = 8.7^0 \text{ with x-axis}}$$

EXAMPLE 4.3

OPENING A DOOR

In figure a force (magnitude 55N) is applied to a door. However, the arm are different in the three parts of the drawing: (a) d_A = 0.80m, (b) d_B = 0.60m and (c) d_C = 0m. Find the torque in each case.



Solution:

Given:

Force F = 55 N

Moment arm d_A = 0.8 m

Moment arm d_B = 0.6 m

Moment arm d_C = 0.0 m

Required: (a) Torque $\vec{\tau}_A = ?$

(b) Torque $\vec{\tau}_B = ?$

(c) Torque $\vec{\tau}_C = ?$

In each case the lever arm is the perpendicular distance between the axis of rotation and the line of action of the force.

(a) Using the definition of torque,

$\tau_A = d_A \times F$

Putting values

$\tau_A = 0.8 \times 55$

$\boxed{\tau_A = 44Nm}$

(b) $\tau_B = d_B \times F$

$\tau_B = 0.6 \times 55$

$\boxed{\tau_B = 33Nm}$

(c) $\tau_C = d_C \times F$

$\tau_C = 0 \times 55$

$\boxed{\tau_C = 0Nm}$

Because the lever arm is different in each case, the torque is different, even though the magnitude of the applied force is the same. In parts a and b, the torques are positive since the forces tend to produce an anti-clockwise rotation of the door. In part c the line of action of force passes through the axis of rotation (the hinge). Hence the lever arm is zero, and the torque is zero.

ASSIGNMENT 4.3:

FORCE ON BOTTLE OPERNER

20Nm torque is required to open a soda bottle. A boy with a bottle opener applies a force perpendicularly at 0.1 m, what is the magnitude of force required.

Solution:

Given:

Applied torque $\tau = 20$ Nm

Moment arm d = 0.1 m

Required: Applied Force F = ?

By the definition of torque,

$$\tau = d \times F$$

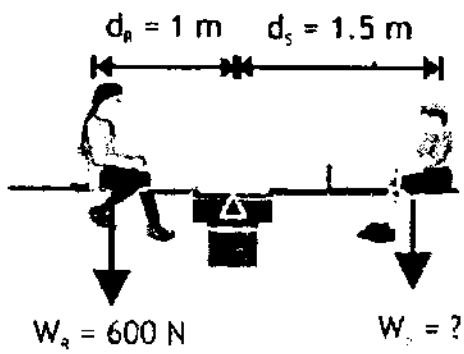
$$F = \frac{\tau}{d} = \frac{20}{0.1}$$

$$\boxed{F = 200N}$$

EXAMPLE 4.4

SEESAW BALANCE

Two children Romiasa and Sanaan are sitting on a seesaw. The see-saw is balanced on a pivot as Romiasa is at 1m and Sanaan at 1.5m from the pivot (as shown in figure). If Romaisa weight is 600N, what is the weight of Sanaan?



Solution:

Given:

Moment arm of Sanaan d_S = 1.5 m

Moment arm of Romiasa d_R = 1m

Weight of Romiasa W_R = 600 N

Required: Weight of Sanaan W_S =?

Romiasa is producing anticlockwise torque, while Sanaan is producing clockwise torque, Therefore, by second condition of equilibrium

$$\tau_{anticlockwise} = \tau_{clockwise}$$

$$\tau_R = \tau_S$$

$$d_R \times W_R = d_S \times W_S$$

Putting values

$$1 \times 600 = 1.5 \times W_S$$

$$W_S = \frac{1 \times 600}{1.5} = \frac{600}{1.5} = 400$$

$$\boxed{W_S = 400N}$$

Extension Exercise 4.2:

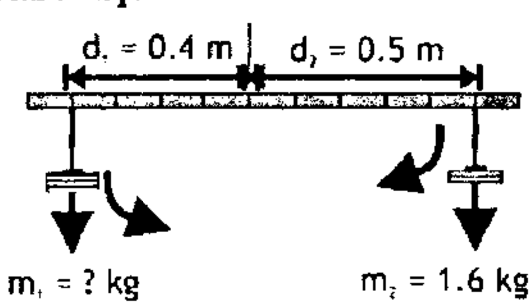
Hint: As weight is given by

$$W = mg \text{ or } m = \frac{W}{g}$$

ASSIGNMENT 4.4:

CALCULATING MASSES

With a beam two mass m_1 and m_2 are suspended at distance 0.4m and 0.5m respectively from suspension point as shown in the figure. Ignoring the weight of the balance, if m_2 = 1.6kg, what is the mass m_1?



Solution:

Given:

Moment arm of body 1, $d_1 = 0.4$ m

Moment arm of body 2, $d_2 = 0.5$ m

Mass of body 2, $m_2 = 1.6$ kg

Required: Mass of body 1, $m_1 = ?$

By second condition of equilibrium

$$\tau_{anticlockwise} = \tau_{clockwise}$$

$$\tau_R = \tau_S$$

$$d_1 \times W_1 = d_2 \times W_2$$

As weight of a body can be given by W = mg, putting in above equation

$$d_1 \times m_1 g = d_2 \times m_2 g$$

"g" will be cancelled out from both sides,

$$d_1 \times m_1 = d_2 \times m_2$$

Putting values

$$0.4 \times m_1 = 0.5 \times 1.6$$

$$m_1 = \frac{0.5 \times 1.6}{0.4} = \frac{0.8}{0.4} = 2$$

$$\boxed{m_1 = 2kg}$$

EXERCISE

MULTIPLE CHOICE QUESTIONS:

(1) Anti-clock wise torque is taken as ________

A. Negative B. positive

C. parallel D. zero

(2) A door requires a minimum torque of 80 Nm in order to open it. What is the minimum distance of the handle from the hinges, if the door is to be pulled with a force at the handle not greater than 100N?

A. 0.6 m	B. 1m
C. 0.4 m	D. 0.8 m

(3) Two children are balanced on opposite sides of a seesaw. If one child leans inward toward the pivot point, her side will

A. rise	B. fall
C. neither rise nor fall	D. none o these

(4) A body in equilibrium must not be

A.at rest	B. moving
C. rotating	D. accelerating

(5) The torque in uniformly rotating fan having blade of length 0.5 m is

A. 0.5 Nm	B. 2 Nm
C. –0.5 Nm	D. 0 Nm

Hint: The body is in dynamic rotational equilibrium.

(6) A force of 100N is applied perpendicularly at 0.5 m, to turn nut of wheel of a bus. The torque acting on nut is

A. 500 Nm	B. 50 Nm
C. 5 Nm	D. 0.005 Nm

(7) The shortest distance between two couple forces is

A. moment arm	B. couple arm
C. radius	D. double moment

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(8) A girl pushes to open a door perpendicularly with a force of 25N at 0.6m from the hinge, the torque is

A. 41.6 Nm   B. 25.6 Nm

C. 15 Nm   D. 0 Nm

(9) The angle at which x and y components of force are equal is

A. 0^0 B. 30^0

C. 45^0 D. 60^0

(10) CM is different from CG, when we have non-uniform

A. shape of object   B. mass of object

C. gravitational force   D. none of these

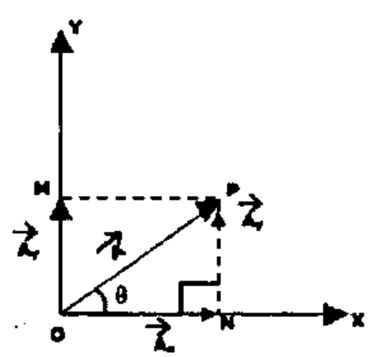
ANSWERS:

1.B	2.D	3.A	4.D	5.D	6.B	7.B	8.C	9.C	10.C

CONCEPTUAL QUESTIONS

(1) Can the rectangular component of the vector be greater than the vector itself? Explain.

Ans. No, it is not possible that the rectangular component of a vector be greater than the vector itself.



Explanation:

The rectangular components of a vector are given by the equation

$$|A| = \sqrt{A_x^2 + A_y^2}$$

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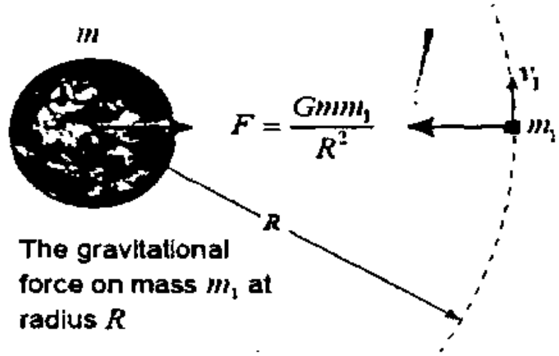


Explanation:

As shown in the figure the gravitational pull of the earth on a satellite moving around it is directed towards the earth. Same is the case for radius which in this case is moment arm for the given force.

Mathematically torque is defined as

$\tau = R \times F$

$\tau = RF\sin\theta$

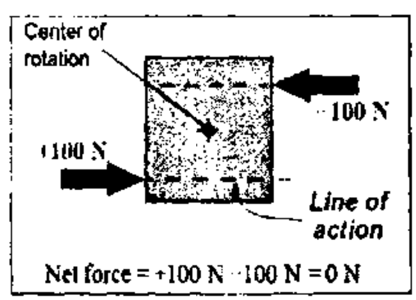
Here the angle between R and F is 180^0 and we know that $\sin 180^0 = 0$

Therefore, no torque will be produced.

(6) Can we have situations in which an object is not in equilibrium, even though the net force on it is zero? Give two examples.

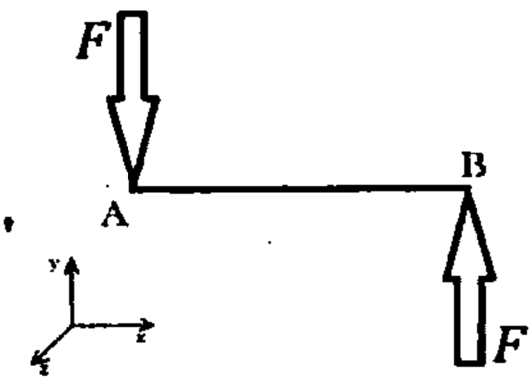
Ans. Yes, we can have a situation in which net force acting on an object is zero but the body is not in equilibrium.

Explanation:



As for complete equilibrium we need both the conditions. If net force acting on the body is zero but net torque is not zero

then the body will not be in equilibrium.



For complete equilibrium we must have following two conditions satisfied

$$\vec{F}_{net} = \sum_{i=1}^{i=n} F_i = 0$$

$$\overrightarrow{\tau_{net}} = \sum_{i=1}^{i=n} \overrightarrow{\tau_i} = 0$$

Two examples are given. In both the cases net force is zero but still we have torque and the body is not in equilibrium. For complete equilibrium, both the conditions must be satisfied.

(7) Why do tightrope walkers carry a long, narrow rod?

Ans. Carrying a narrow rod helps the walker increase their rotational inertia, which aids in maintaining stability while walking over the narrow rope. The rod also adds more weight below the centre of gravity of the walker, which is another bonus for maintaining balance.

Whereas A_x and A_y are rectangular components of vector "A".

The rectangular component can only be equal to a vector itself if the vector is along the direction of any of the rectangular component but can never be greater.

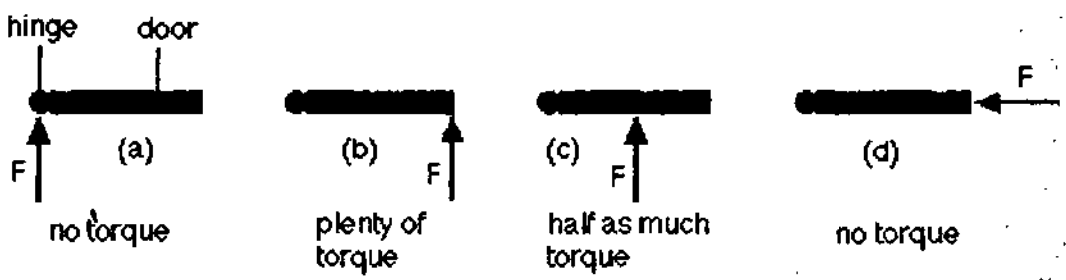
(2) Explain why door handles are not put near hinges?

Ans. The door handles are not put near hinges because it will reduce the moment arm to zero causing the torque to be zero and hence no rotational effect will produce.

Explanation:

The torque can be given by

$\tau = d \times F$



If the force is applied on hinges no torque will be produced as then product of moment arm and force will be zero from above equation (Figure a)

(3) Can a small force ever exert a greater torque than a larger force? Explain.

Ans. May or may not be. The torque acting on the body not only depends upon force but also other quantities (moment arm and angle between force and moment arm)

Explanation:

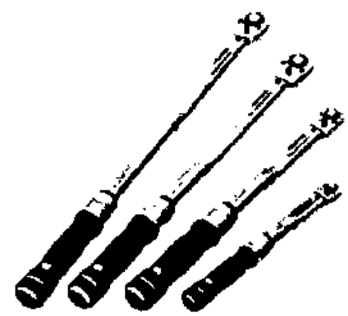
The mathematical form of torque is given by

$\tau = d \times F$

If you apply a smaller force that is perpendicular to the moment arm, it will produce a larger torque (figure b above) than a greater force applied on or near hinges (figure a, c and d) But if we apply both the forces on same point then the larger force will produce larger torque.

(4) Why it is better to use a long spanner rather than a short one to loosen a rusty nut?

Ans. Increasing length of spanner will increase the amount of torque produced which will help to loosen a rusty nut.



Explanation:

The mathematical form of torque is given by

$\tau = d \times F$

As shown in the figure, the lengthy spanner will lose a rusty nut easily than the smaller one. It is because the larger the length of the spanner the greater will be the torque and vice versa.

(5) The gravitational force acting on a satellite is always directed towards the centre of the earth. Does this force exert torque on satellite?

Ans. No, this force does not exert any torque on the satellite as force (gravitational F_g) is parallel to the radius (moment arm R)

Explanation:

By carrying a rod (it's called a balancing pole, more specifically) horizontally in their hands, the tightrope walker increases his moment of inertia, i.e., he minimizes his body's "rotation" around the rope. The length of the rod also plays an important role: the longer the rod, the better it is for stability. This is because it spreads the combined mass over the rope (weight of the walker + weight of the rod) far away from the pivot point (the feet of the walker) The rod reduces angular acceleration of the tightrope walker as more torque is required to rotate the walker. This means that if the walker tips over, he would do that very slowly and therefore have more time to correct his stance/gait.

(8) Why does wearing high-heeled shoe sometimes cause lower back pain?

Ans. High-heeled shoes force the centre of mass of the person wearing to move forward from its normal position. To maintain balance, the person must move the centre of mass back again, usually by leaning the shoulders backward. This effort can cause fatigue in the back muscles.

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Explanation:

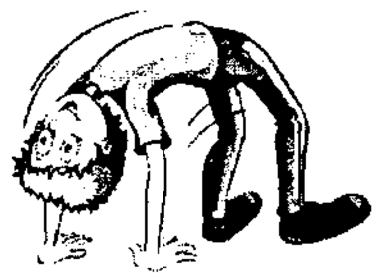
Normally the centre of gravity of a human is about an inch below the navel in the centre of the body. When you use high-heeled shoes that changes your centre of gravity and in sometimes it take the centre of gravity out of your body. Due to which the equilibrium of body disturbs and soon you feel lower back pain.

(9) Why is it more difficult to lean backwards? Explain.

Ans. It is difficult to lean backward because your body has to maintain its balance when you lean anyway.

Explanation:

This self-balancing system of your body enables you to prevent yourself from toppling over when you stand upright or lean forward or backward.



(10) Can a single force be applied to a body change both its translational and rotational motion? Explain.

Ans. Yes, if applied outside the centre of mass.

Explanation:

Such a force will net only cause translational motion, but will also generate a torque, causing rotation as well. In the given figure, a footballer kicks the football. It starts translational motion in the forward direction.

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At the same time football also rotates about its own axis. So, a single force (kick of footballer) changed the translational as well as rotational motion of the football.

(11) Two forces produce the same torque. Does it follow that they have the same magnitude? Explain.

Ans. May or may not be. The torque acting on the body not only depends upon force but also other quantities (moment arm and angle between force and moment arm)

Explanation:

The mathematical form of torque is given by

$\tau = r \times F$

$\tau = rF\sin\theta$

If you apply two equal forces but at different angles (θ) or at different positions (r), the torque produced will be different for same forces.

NUMERICAL PROBLEMS

(1) To open a door force of 15N is applied at 30° to the horizontal, find the horizontal and vertical components of force.

Solution:

Given:

Force F = 15 N

Angle $\theta = 30°$

Required: Horizontal component $F_x = ?$

Vertical component $F_y = ?$

Horizontal component of force is given by

$F_x = F\cos\theta$

Putting values

$F_x = 15\cos 30°$

$F_x = 15 \times 0.866 = 12.99$

$\boxed{F_x = 12.99N}$

Vertical component of force is given by

$F_y = F\sin\theta$

Putting values

$F_y = 15\sin 30°$

$F_y = 15 \times 0.5 = 7.5$

$\boxed{F_y = 7.5N}$

(2) A bolt on a car engine needs to be tightened with a torque of 40Nm. You use a 25cm long wrench and pull on the end of the wrench perpendicularly. How much force do you have to exert?

Solution:

Given:

Torque $\tau = 40Nm$

Length of wrench r = 25 cm = 0.25 m

Angle $\theta = 90°$

Required: Force F =?

The mathematical form of torque is given by

$\tau = r \times F = rF\sin\theta$

Putting values

$40 = 0.25 \times F \times \sin 90°$

As sin 90 = 1

$$F = \frac{40}{0.25 \times 1} = \frac{40}{0.25} = 160$$

$\boxed{F = 160N}$

(3) Sana whose mass is 43kg, sits 1.8m from the centre of a seesaw. Faiz whose mass is 52kg wants to balance Sana. How far from the centre of the seesaw should Faiz sit?

Solution:

Given:

Mass of sana, $m_s = 43kg$

Moment arm of sana, $d_S = 1.8m$

Mass of Faiz, $m_F = 52kg$

Required: Moment arm of Faiz, $d_F = ?$

From 2nd condition of equilibrium

$T_F = T_S$

$d_F m_F = d_S m_S$

Putting values

$d_F \times 52 = 1.8 \times 43$

$d_F = \dfrac{1.8 \times 43}{52} = 1.488 = 1.5$

$\boxed{d_F = 1.5\text{m}}$

(4) Two kids of weighing 300N and 350N are sitting at the ends of 6m long see-saw. The seesaw is pivoted at its centre. Where would a third kid sit so that the see-saw is in equilibrium in the horizontal position? The weight of third kid is 250N. (Ignore the weight of see-saw)

Solution:

Given:

Weight of first kid $W_1 = 300N$

Weight of second kid $W_2 = 350N$

Length of seesaw $L = 6m$ ($d_1 = 3m$ and $d_2 = 3m$)

Weight of third kid $W_3 = 250N$

Required: Position of 3rd kid $d_3 = ?$

The third kid must sit towards the lighter weight (on side of 1st kid) to obtain equilibrium as the see-saw is pivoted at its centre.

Let the 1st kid (and hence 3rd) sit on left side of see-saw producing anti-clockwise torque then from second condition of equilibrium

$\tau_{anticlockwise} = \tau_{clockwise}$

$\tau_1 + \tau_3 = \tau_2$

$d_1 \times W_1 + d_3 \times W_3 = d_2 \times W_2$

Putting values

$3 \times 300 \times d_3 \times 250 = 3 \times 350$

$$d_3 = \frac{3\times350-3\times300}{250} = \frac{1050-900}{250} = \frac{150}{250} = 0.6$$

$\boxed{d_3 = 0.6\text{m from pivot}}$

(5) Two children push on opposite sides of a door during play. Both push horizontally and perpendicular to the door. One child pushes with a force of 20N at a distance of 0.60m from the hinges, and the second child pushes at a distance of 0.50m. What force must the second child exert to keep the door from moving? Assume friction is negligible.

Solution:

Given:

Force applied by one child $F_1 = 20$ N

Moment arm of one child $d_1 = 0.60$ m

Moment arm of second child $d_2 = 0.50$ m

Required: Force applied by second child $F_2 = ?$

From second condition of equilibrium

$\tau_{anticlockwise} = \tau_{clockwise}$

$\tau_R = \tau_S$

$d_1 \times F_1 = d_2 \times F_2$

Putting values

$$F_2 = \frac{d_1 \times F_1}{d_2}$$

$$F_2 = \frac{0.60 \times 20}{0.5} = 24$$

$$\boxed{F_2 = 24N}$$

(6) A construction crane lifts building material of mass 1500kg by moving its crane arm, calculate moment of force when moment arm is 20m. After lifting the crane arm, which reduces moment arm to 12m calculate moment.

Solution:

Given:

Mass of material m = 1500kg

Moment arm $d_1 = 20$ m

Moment arm $d_2 = 12$ m

Required: Moment arm $\tau_1 = ?$

Moment arm $\tau_2 = ?$

First, we will find weight (force) of the material

$W = mg = 1500 \times 9.8 = 14,700$

$W = 14,700N$

Now using mathematical relation for moment arm

$\tau_1 = d_1 \times W = 20 \times 14,700 = 294,000$

$$\boxed{\tau_1 = 2.94 \times 10^5 \text{ Nm}}$$

$\tau_2 = d_2 \times W = 12 \times 14,700 = 176,400$

$$\boxed{\tau_2 = 1.76 \times 10^5 \text{ Nm}}$$

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Unit 5

Gravitation

Q.1: State and explain the law of Universal Gravitation. Also show that the law obeys Newton's third law of motion.

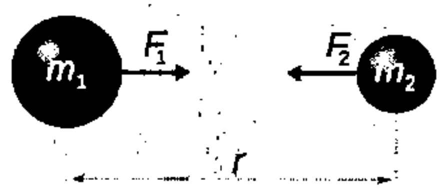
Ans. **Newton's law of Universal Gravitation:**

"*Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres*".

Mathematically,

$F_g \propto m_1 m_2$

$F_g \propto \frac{1}{r^2}$



Combining both the equations

$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

$$F_g \propto \frac{m_1 m_2}{r^2}$$

Replacing proportionality with constant G called gravitational constant and is equal to $6.673 \times 10^{-11} Nm^2kg^{-2}$.

$$F_g = G\frac{m_1 m_2}{r^2}$$

Note:

This force is always attractive and can never be repulsive. It does not depend upon the medium between the masses but only on their masses and separation between them.

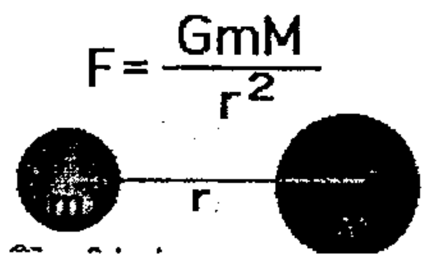
Newton's Third Law of Motion and Universal Gravitation:

We can see that the force acting on mass m_1 due to mass m_2 is F_2. Also, the force acting on mass m_2 due to mass m_1 is same force F_1 both these forces are equal but in magnitude opposite in direction. Therefore, we can say that the forces acting on two bodies due to gravitation force is the example of action and reaction forces as shown in the figure.

Mathematically,

$$F_1 = G\frac{m_1 m_2}{r^2} = F_2$$

These two forces act like action and reaction which are equal to each other in magnitude but opposite in direction. It means that Newton's universal law of gravitation obeys Newton's 3rd law motion.



Q.2: Determine the mass of Earth by applying law of gravitation.

Ans. The determination of gravitational constant helped scientists to calculate the mass of earth, sun and other celestial objects.

Let us consider we have two bodies one Earth having mass "M" and another any other body of mass "m". The gravitational force of attraction between these two bodies will be given by

$$F_g = G\frac{mM}{r_E^{\ 2}}$$

Now as force of gravity is equal to the weight of the body so

$$W = F_g = mg = G\frac{mM}{r_E^{\ 2}}$$

$$\cancel{m}g = G\frac{\cancel{m}M}{r_E^{\ 2}}$$

$$M = \frac{gr_E^2}{G}$$

Putting values of constants $g=9.8ms^{-2}$, $r_E=6.4\times10^6m$ and $G = 6.673\times10^{-11}Nm^2kg^{-2}$.

$$M = 5.97\times10^{24}kg$$

Q.3: What is gravitational field and gravitational field strength? Show that the weight of an object changes with location. Also, how is the value of 'g' changing by going to higher altitude? Write the relevant formula.

Ans. **Gravitational field:**

The region around a body of mass "m" where it attracts another body toward itself OR where it experiences a gravitational force by another body.

Gravitational field of earth is the region around it where it attracts every other body towards its centre.

Gravitational field strength:

At any point, Earth's gravitational field can be described by the gravitational field strength, abbreviated g.

The value of g is equal to the magnitude of the gravitational force exerted on a unit mass at that point.

Mathematically,

$$g=\frac{F}{m}$$

The gravitational field (g) is a vector with a magnitude of g that points in the direction of the gravitational force.

Geo potential Altitude above Sea Level - h - (m)	Temperature - t - (°C)	Acceleration of Gravity - g - (m/s²)
-1000	21.50	9.810
0	15.00	9.807
1000	8.50	9.804
2000	2.00	9.801
3000	-4.49	9.797
4000	-10.98	9.794
5000	-17.47	9.791
6000	-23.96	9.788
7000	-30.45	9.785
8000	-36.94	9.782
9000	-43.42	9.779
10000	-49.90	9.776
15000	-56.50	9.761
20000	-56.50	9.745
25000	-51.60	9.730
30000	-46.64	9.715
40000	-22.80	9.684
50000	-2.5	9.654
60000	-26.13	9.624
70000	-53.57	9.594
80000	-74.51	9.564

Weight changes with location:

The value of g changes with changing altitudes from sea level which also changes the weight of the body by W=mg

Newton's law of universal gravitation shows that the value of g depends on mass and distance from the centre of earth.

Newton's law of universal gravitation the gravitational force on an object of mass "m" at a distance "r" away from the centre of earth is given by

$$F_g=G\frac{mM}{r_E^2}$$

The gravitational field strength F_g by Newton's second law is

F = W = mg

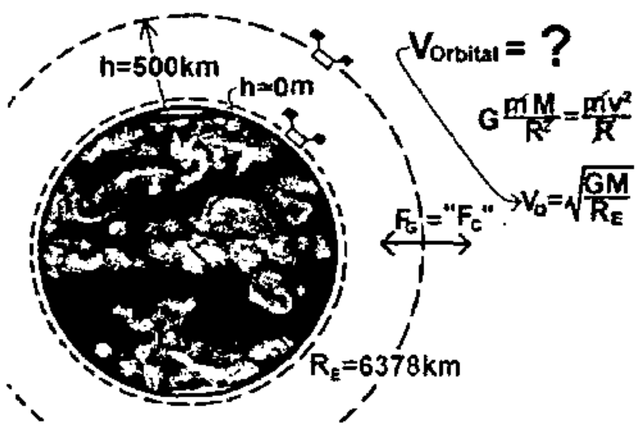
Comparing both the equations will give value of "g"

$$g = \frac{GM_E}{r^2}$$

Inserting the known values of m = 6×10^{24} kg and r = 6.4×10^{6} m along with G = 6.67×10^{-11} Nm kg we get g = $9.8 m/s^2$.

Q.4: Derive the formula for the orbital speed of an artificial satellite.

Ans. *The satellite revolves around the earth in a circular orbit.* The centripetal force on the satellite is provided by the gravitational attractive force given by



$$F_c = \frac{mv^2}{r} \qquad F_g = \frac{GmM}{r^2}$$

Combining both the equations

$$F_c = F_g = \frac{GmM}{r^2} = \frac{mv^2}{r}$$

$$\frac{G\cancel{m}M}{r^{\cancel{2}}} = \frac{\cancel{m}v^2}{\cancel{r}}$$

$$v = \sqrt{\frac{GM}{r}}$$

Whereas, G is gravitational constant, M is mass of earth (or any other planet around which the satellite revolves) and "r" is the distance between satellite and centre of earth ($r = R_E + h$) as shown in the figure.

For a satellite moving around the earth at a height of 500 km, the orbital speed of satellite will be 7600 ms^{-1} or 17000 miles per hour.

Examples and Assignments:

EXAMPLE 5.1

CAN YOU ATTRACT ANOTHER PERSON GRAVITATIONALLY

Suppose you have mass of 40 kg and a 45 kg person is sitting on a bench close to you, such that the distance between centres of you and the person is 0.5 m. Estimate the magnitude of the gravitational force you exert on that person.

Solution:

Given:

Mass, $m_1 = 40$ kg

Mass, $m_2 = 45$ kg

Distance, $r = 0.5$ m

Gravitational constant, $G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

Required: Gravitational Force, $F_g = ?$

Using Newton's law of universal gravitation

$$F_g = G\frac{m_1 m_2}{r^2}$$

Putting values

$$F_g = 6.673\times10^{-11}\frac{40\times45}{(0.5)^2} = \boxed{4.8\times10^{-7}N}$$

This means we attract each other but a force of about 10^{-7} N is unnoticeably small unless extremely sensitive instruments are used. Even very large-scale objects like ships and building have very small gravitational attraction.

ASSIGNMENT 5.1:

GRAVITATIONAL FORCE ON MOON

The mass of earth is 6×10^{24} kg and that of the moon is 7.4×10^{22} kg. If the distance between the earth and the moon is 3.84×10^{5} km, calculate the force exerted by the earth on the moon.

Solution:

Given:

Mass of earth $m_1 = 6 \times 10^{24}$ kg

Mass of moon $m_2 = 7.4 \times 10^{22}$ kg

Distance $r = 3.84 \times 10^{5}$ km $= 3.84 \times 10^{8}$ m

Gravitational constant $G = 6.673\times10^{-11} Nm^2kg^{-2}$

Required: Gravitational Force F_g =?

Using Newton's law of universal gravitation

$$F_g = G\frac{m_1 m_2}{r^2}$$

Putting values

$$F_g = 6.673\times10^{-11}\frac{6\times10^{24}\times7.4\times10^{22}}{(3.84\times10^{8})^2} = \boxed{2\times10^{20}N}$$

EXAMPLE 5.2

MASS OF JUPITER

Jupiter is the largest planet in the solar system. Radius of Jupiter is $r = 7.15 \times 10^7$m, the acceleration due to gravity on Jupiter is 24.7 N/kg. Calculate the mass of Jupiter.

Solution:

Given:

Radius of Jupiter $r = 7.15 \times 10^7$ m

Acceleration due to gravity on Jupiter $g = 24.7$N/kg

Gravitational constant $G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

Required: Mass of Jupiter m =?

The mass of a planet or star can be calculated by the following formula

$$m = \frac{gr^2}{G}$$

Putting values

$$m = \frac{24.7(7.15 \times 10^7)^2}{6.673 \times 10^{-11}} = \boxed{1.89 \times 10^{27} kg}$$

Thus, the mass of Jupiter is about 300 times the mass of the earth.

ASSIGNMENT 5.2:

MASS OF MOON

If the radius of the moon is 1.74×10^6 m and have acceleration due to gravity on its surface as 1.6 ms^{-2}. Calculate the mass of moon.

Solution:

Given:

Radius of moon r $=1.74 \times 10^6$ m

Acceleration due to gravity on moon g$=1.6\text{ms}^{-2}$

Gravitational constant $G=6.673\times10^{-11}Nm^2kg^{-2}$

Required: Mass of moon m =?

The mass of a planet or star can be calculated by the following formula

$$m=\frac{gr^2}{G}$$

Putting values

$$m=\frac{1.6(1.74\times10^6)^2}{6.673\times10^{-11}}=\boxed{7.262\times10^{22}kg}$$

EXAMPLE 5.3

VALUE OF 'g' AT SUN'S SURFACE

What is the free-fall acceleration at the surface of the sun? As mass of Sun is 1.99 × 10^{30} kg and having radius of 6.96 × 10^8 m.

Solution:

Given:

Mass of sun M = 1.99×10^{30} kg

Radius of sun R = 6.96×10^8 m

Gravitational constant $G=6.673\times10^{-11}Nm^2kg^{-2}$

Required: Free fall acceleration at sun g =?

Acceleration due to gravity is given by

$$g=\frac{GM}{R^2}$$

Putting Values

$$g = \frac{6.673\times10^{-11}\times1.99\times10^{30}}{(6.69\times10^{8})^2} = \boxed{274ms^{-2}}$$

Notice that the mass of the Sun is almost a million times more than the mass of the Earth and having gravitational acceleration of about 30 times that of earth.

ASSIGNMENT 5.3:

FREE FALL AT MOON

An astronaut of mass 65.0 kg (weighing 637 N on earth) is walking on the surface of the Moon, which has a mean radius of 1.74 × 10^6 m and a mass of 7.35 × 10^{22} kg. What is the weight of the astronaut on moon? What is the free-fall acceleration at the surface of the moon?

Solution:

Given:

Mass of astronaut m = 65.0 kg

Mass of Moon M = 7.35 × 10^{22} kg

Weight of astronaut on moon W_m =?

Weight of astronaut on earth = 637 N

Radius of moon R_m = 1.74 × 10^6 m

Gravitational constant $G = 6.673\times10^{-11} Nm^2kg^{-2}$

Required: Free fall acceleration at moon g_m =?

Acceleration due to gravity is given by

$$g_m = \frac{GM_m}{R_m^2}$$

Putting values

$$g_m = \frac{6.673\times10^{-11}\times7.35\times10^{22}}{(1.74\times10^6)^2} = \boxed{1.62ms^{-2}}$$

Weight of astronaut can be found by the following relation

$W_m = mg_m$

Putting values

$W_m = 65.0\times1.61 = \boxed{105.3N}$

EXAMPLE 5.4

METEOROID IN EARTH'S FIELD

A meteoroid (a chunk of rock) is at 4.4 × 10^7 m from the earth, what is the value of free fall acceleration 'g' at this point due to earth.

Solution:

Given:

Radius of earth $R_E = 6.4\times10^6 m$

Acceleration due to gravity g = 9.8 ms^{-2}

Height of meteoroid $h = 4.4\times10^7 m = 44\times10^6 m$

Required: Acceleration due to gravity g_h =?

The value of "g_h" above the surface of earth can be calculated by

$$g_h = \frac{g(R_E)^2}{(R_E+h)^2}$$

Putting values in above equation

$$g_h = \frac{9.8(6.4\times10^6)^2}{(6.4\times10^6+44\times10^6 m)^2} = \boxed{0.16ms^{-2}}$$

Extension Exercise 5.1: Hint:

Using formula $g_J = \frac{GM_J}{R_J^2}$ and entering values $G = 6.673\times10^{-11}Nm^2kg^{-2}$, $M_J = 1.89\times10^{27}kg$ and $R_J = 7.15\times10^7 m$, we will get value of g_J which is equal to 24.66 ms^{-2}.

ASSIGNMENT 5.4:

VALUE OF "g" AT SPECIFIC HEIGHT

Calculate the value of g at 1000 km and 35900 km above the earth surface.

Solution:

Given:

Height h_1 = 1000 km = 10^3 km = 10^6 m

Height h_2 = 35,900km=35.9×10^3km=35.9×10^6m

Required: Acceleration due to gravity $g_{1h} = ?$

Acceleration due to gravity $g_{2h} = ?$

The value of "g_h" above the surface of earth can be calculated by

$$g_h = \frac{g(R_E)^2}{(R_E+h)^2}$$

Putting values in above equation

$$g_{1h} = \frac{9.8(6.4\times10^6)^2}{(6.4\times10^6+1\times10^6 m)^2} = \boxed{7.33ms^{-2}}$$

$$g_{2h} = \frac{9.8(6.4\times10^6)^2}{(6.4\times10^6+35.9\times10^6 m)^2} = \boxed{0.22ms^{-2}}$$

EXAMPLE 5.5

SPEED OF EARTH AROUND SUN

The mass of the Sun is 1.99×10^{30} kg, and the radius of the Earth's orbit around the Sun is 1.5×10^{11}m. From this, calculate the orbital speed of the Earth.

Solution:

Given:

Mass of sun $m_s = 1.99 \times 10^{30}$ kg

Radius of earth's orbit R $=1.5\times10^{11}$ m

Gravitational constant $G = 6.673\times10^{-11} Nm^2kg^{-2}$

Required: Orbital speed v =?

The orbital speed is given by

$$v = \sqrt{G\frac{m_s}{r}}$$

Putting values

$$v = \sqrt{6.673\times10^{-11}\frac{1.99\times10^{30}}{1.5\times10^{11}}}$$

$$v = 3.0\times10^{4} ms^{-1} = \boxed{30kms^{-1}}$$

ASSIGNMENT 5.5

ORBITAL SPEED OF A SATELLITE

If a satellite orbits the earth at 2,000 km above sea level, how fast will the orbiting satellite travel to maintain a circular orbit?

Solution:

Given:

Height of satellite h = 2,000 km = 2×10^6 m

Radius of earth $R_E = 6.4 \times 10^6$ m

Radius of satellite $r = R_E + h = 8.4 \times 10^6$ m

Mass of earth $M_E = 6 \times 10^{24}$ kg

Gravitational constant $G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

Required: Orbital speed v =?

The orbital speed is given by

$$v = \sqrt{G\frac{M_E}{r}}$$

Putting values

$$v = \sqrt{6.673 \times 10^{-11}\frac{6 \times 10^{24}}{8.4 \times 10^6}}$$

$$v = 6{,}890 ms^{-1} = \boxed{6.89 kms^{-1}}$$

EXERCISE

Multiple choice questions:

(1) Two masses are separated by a distance r. If both masses are doubled, the force of interaction between the two masses changes by a factor

A. 2 B. 4

C. 1/2 D. 1/4

(2) The radius of earth R_E is

A. 9.8 m B. 6.67×10^{-11} m

C. 6×10^{24} m D. 6.4×10^6 m

(3) The S.I. unit for gravitational constant "G" is

A. $N\ kg^2$ B. $N\ m^2\ kg^{-2}$

C. $N\ m^2\ kg^2$ D. $N\ m^{-2}\ kg^2$

(4) What is the mass on planet Mercury of an object that weighs 784N on the earth's surface?

A. 80.0 kg B. 118 kg

C. 784 kg D. More information needed

(5) An object is orbiting a planet with orbital speed v, if the radius is same and mass is increased 4 times, by what factor orbital speed will change

A. 2 B. 4

C. 1/2 D. 1/4

(6) The value of 'g' at the surface of the moon is;

A. $9.8\ ms^{-2}$ B. $1.63\ ms^{-2}$

C. $4.9\ ms^{-2}$ D. $8.9\ ms^{-2}$

(7) The value of 'g' ________ with altitude

A. increases B. decreases

C. gets ZERO D. remains the same

(8) When a body is moved from sea level to the top of a mountain, there is change in the bodies.

A. mass B. weight

C. both mass and weight D. none

(9) The value of 'g' at equator is

A. Same as at poles B. Larger than at poles

C. Smaller than at poles D. none

ANSWERS:

1.B	2.D	3.B	4.A	5.A	6.B	7.B	8.B	9.C

CONCEPTUAL QUESTIONS

(1) If there is an attractive force between all objects, why don't we feel ourselves gravitating toward nearby massive buildings?

Ans. Yes, there is an attractive force between our body having mass "m" and a nearby massive building having mass "M" but its magnitude is very small to observe.

Explanation:

Mathematically force of attraction between two bodies is given by

$$F_g = G\frac{Mm}{r^2}$$

Let us the mass of a nearby building is 800,000 kg and my mass is 70 kg. The separation is 1m and value of G is $G = 6.673\times10^{-11}Nm^2kg^{-2}$. Putting in above equation

$$F_g = 6.67\times10^{-11}Nm^2kg^{-2}\frac{70\times800,000}{1^2}$$

$$F_g = 3.73\times10^{-3}N = 0.00373N$$

0.00373 N is very small force to detect. That is why we do not feel it but is present always and between all objects having mass.

(2) Does the sun exert a larger force on the Earth than that exerted on the sun by the Earth? Explain.

Ans. No, both the sun and earth exert same amount of force on each other mathematically given by

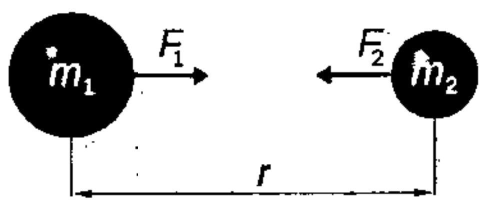
$$F_g = \frac{GM_EM_S}{r^2}$$

Explanation:

Let us F_1 be the force exerted on sun by the earth and F_2 is the force exerted on earth by the sun then mathematically

$$F_1 = F_2 = \frac{GM_E M_S}{r^2}$$

Both the forces act like action and reaction and are always equal to each other but are oppositely directed as shown in the figure.



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

(3) What is the importance of gravitational constant 'G'? Why is it difficult to calculate?

Ans. The gravitational constant is the proportionality constant used in newton's law of universal gravitation and is commonly denoted by G.

It's value is very small, so a very sensitive device is required to calculate it. That's why it is difficult to calculate under normal condition.

(4) If Earth somehow expanded to a larger radius, with no change in mass, how would your weight be affected? How would it be affected if Earth instead shrunk?

Ans. Increasing radius of earth will decreases your weight while decreasing radius will increase your weight.

Explanation:

Weight of a body having mass m is given by

W = mg

As mass of a body remains constant so changing value of gravitational acceleration g will change weight of a body. The value of g is given by

$$g = \frac{GM_E}{R_E^2}$$

It means that g is inversely proportional to the square of the radius of earth. So, if earth expands to a larger radius its g will decrease and hence weight of the body will also decrease. In other case if earth shrinks to a smaller radius, the value of g will increase and will increase the weight of the body. As we know that due to rotation of earth about its own axis, the equatorial radius is larger than the polar radius. Because of this value of g is larger at poles than at equator.

(5) What would happen to your weight on earth if the mass of the earth doubled, but its radius stayed the same?

Ans. The weight of a body will become double if mass of earth doubles and radius stay the same.

Explanation:

Weight of a body having mass m is given by

W = mg

As mass of a body remains constant so changing value of gravitational acceleration g will change weight of a body. The value of g is given by

$$g = \frac{GM_E}{R_E^2}$$

Now changing mass of earth will change g and hence weight of the body. Increasing mass to its double will double the value of g, which will also double the value of weight of that body if radius of earth stays the same.

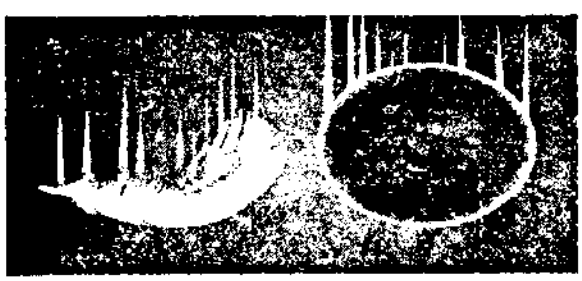
(6) Why lighter and heavier objects fall at the same rate toward the earth?

Ans. The lighter and heavier objects fall at the same rate towards the earth because value of acceleration due to gravity is independent of mass of the falling object but depends upon mass and radius of earth given by

$$g = \frac{GM_E}{R_E^2}$$

Explanation:

For freely falling objects, the only force acting is gravity which acts at a constant rate bring a change in velocity at a constant rate given by 9.8 ms^{-2}. This means that the same force will act on a falling ball as acts on a feather. In the absence of air both will fall at the same speed as shown in the figure.



(7) The value of 'g' changes with location on earth, however we take same value of 'g' as 9.8 ms^{-2} for ordinary calculations. Why?

Ans. As we know that earth revolves around itself, causes bulging of earth at equator which leads to an increase in equatorial radius as compared to polar radius.

Altitude (km)	a (m/s^2)	Altitude Example
0.0	9.8	Mean Earth radius
8.8	9.8	Mt. Everest
36.6	9.7	Highest manned balloon
400	8.7	Space shuttle orbit
35 700	0.2	Communications satellite

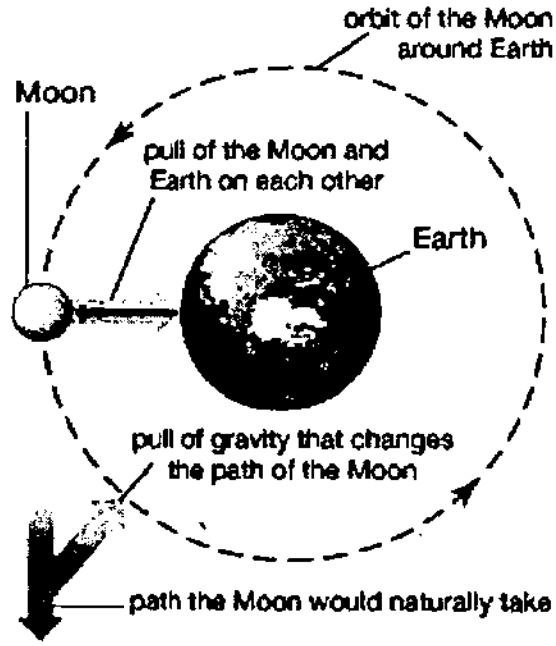
$$g = \frac{GM_E}{R_E^2}$$

So, changing radius changes g.

The second reason is that different parts of earth are at different height from sea level which also affects value of g. At Mount Everest or Murree, the value of g will be smaller as compared to Karachi.

(8) Moon is attracted by the earth, why it does not fall on earth?

Ans. The moon revolves around the earth in a circular orbit with a tangential velocity V as shown in the figure.



Due to this velocity the moon always tries to move away from the circular orbit. However, the gravitational attraction between moon and earth compels the moon to revolve in a circular orbit. The moon is under two forces named centripetal force (keeps the moon in circular orbit) and centrifugal force (tries to move away the moon from the circular orbit) So, the centrifugal force does not allow the moon to fall towards earth and keeps the moon to move in a circular orbit as shown in the figure.

(9) Why for same height larger and smaller satellites must have same orbital speeds?

Ans. The orbital speed of a satellite depends upon the mass and radius of the earth (or any other planet around which the satellite revolves) given by the relation

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$$v = \sqrt{\frac{GM_E}{r}} = \sqrt{\frac{GM_E}{R_E + h}}$$

Explanation:

It is clear from the relation that mass of the satellite has no place in finding the orbital velocity of a satellite revolving around the earth, which means that a lighter and a heavier satellite will move in the same orbital speed at same height (h).

NUMERICAL PROBLEMS

(1) Pluto's moon Charon is unusually large considering Pluto's size, giving them the character of a double planet. Their masses are 1.25×10^{22}kg and 1.9×10^{21}kg, and their average distance from one another is 1.96×10^{4}km. What is the gravitational force between them?

Solution:

Given:

Mass of Pluto $M_P = 1.25 \times 10^{22}$ kg

Mass of moon $M_m = 1.9 \times 10^{21}$ kg

Separation between Pluto and its moon

$R = 1.96\times10^{4}$ km $= 1.96 \times 10^{7}$ m

Gravitational constant $G = 6.673\times10^{-11} Nm^2kg^{-2}$

Required: Gravitational force F_g =?

The gravitational force is given by

$$F_g = \frac{GM_pM_m}{R}$$

Putting values

$$F_g = 6.67\times10^{-11}\frac{1.25\times10^{22}\times1.9\times10^{21}}{(1.96\times10^{7})^2}$$

$$\boxed{F_g = 4.12\times10^{18}N}$$

(2) The mass of Mars is 6.4×10²³kg and having radius of 3.4×10⁶m. Calculate the gravitational field strength (g) on Mars surface.

Solution:

Given:

Mass of Mars M = 6.4×10^{23} kg

Radius of Mars R = 3.4×10^{6} m

Gravitational constant $G = 6.673\times10^{-11}Nm^2kg^{-2}$

Required: Gravitational field strength g =?

The gravitational strength g is given by

$$g = \frac{GM}{R^2}$$

Putting values

$$g = 6.67\times10^{-11}\frac{6.4\times10^{23}}{(3.4\times10^{6})^2} = \boxed{3.685ms^{-2}}$$

(3) Titan is the largest moon of Saturn and the only moon in the solar system known to have a

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substantial atmosphere. Find the acceleration due to gravity on Titan's surface, given that its mass is 1.35×10^{18} kg and its radius is 2570 km.

Solution:

Given:

Mass of Titan M = 1.35×10^{18} kg

Radius of Titan R = 2570 km = 2.57×10^{6} m

Gravitational constant $G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

Required: Gravitational field strength g =?

The gravitational strength g is given by

$$g = \frac{GM}{R^2}$$

Putting values

$$g = 6.67 \times 10^{-11} \frac{1.35 \times 10^{18}}{(2.57 \times 10^{6})^2}$$

$$\boxed{g = 1.36 \times 10^{-5} ms^{-2}}$$

(4) At which altitude above Earth's surface would the gravitational acceleration be 4.9 ms^{-2}?

Solution:

Given:

Gravitational acceleration g = 4.9 ms^{-2}

Mass of earth $M_E = 6 \times 10^{24}$ kg

Radius of earth $R_E = 6.4 \times 10^{6}$ m

Gravitational constant $G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

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Required: Height h =?

The acceleration due to gravity is given by the relation

$$g=\frac{GM_E}{(R_E+h)^2} \Rightarrow h=\sqrt{\frac{GM_E}{g}}-R_E$$

Putting values

$$h=\sqrt{\frac{6.67\times10^{-11}\times6\times10^{24}}{4.9}}-6.4\times10^6$$

$$\boxed{h=2.66\times10^6 m}$$

(5) Assume that a satellite orbits Earth 225km above its surface. Given that the mass of Earth is 6×10^{24}kg and the radius of Earth is 6.4×10^6m, what is the satellite's orbital speed?

Solution:

Given:

Height h = 225 km = 2.25×10^6m

Mass of earth $M_E = 6\times10^{24}$ kg

Radius of earth $R_E = 6.4\times10^6$ m

Gravitational constant $G=6.673\times10^{-11}Nm^2kg^{-2}$

Required: Orbital speed V =?

The satellite's orbital speed is given by the relation

$$v=\sqrt{\frac{GM_E}{R_E+h}}$$

Putting values

$$v=\sqrt{\frac{6.67\times10^{-11}\times6\times10^{24}}{6.4\times10^{6}+2.25\times10^{6}}}$$

$$v=7.77\times10^{3}ms^{-1}=\boxed{7.7km^{-1}}$$

(6) The distance from centre of earth to centre of moon is 3.8×10^8m. Mass of earth is 6×10^{24}kg. What is the orbital speed of moon?

Solution:

Given:

Mass of earth $M_E = 6 \times 10^{24}$ kg

Gravitational constant $G=6.673\times10^{-11}Nm^2kg^{-2}$

Distance between moon and centre of earth

$R_E + h = 3.8 \times 10^8$ m

Required: Orbital speed V =?

The satellite's orbital speed is given by the relation

$$v=\sqrt{\frac{GM_E}{R_E+h}}$$

Putting values

$$v=\sqrt{\frac{6.67\times10^{-11}\times6\times10^{24}}{3.8\times10^{8}}}$$

$$v=1.02\times10^{3}ms^{-1}=\boxed{1.02km^{-1}}$$

(7) The Hubble space telescope orbits Earth ($m=6\times10^{24}$kg) with an orbital speed of 7.6×10^{3}m/s. Calculate its altitude above Earth's surface.

Solution:

Given:

Mass of earth $M_E = 6 \times 10^{24}$ kg

Gravitational constant $G = 6.673\times10^{-11} Nm^2kg^{-2}$

Distance between moon and centre of earth

$R_E = 6.4 \times 10^6$ m

Orbital speed $V = 7.6 \times 10^3$ ms^{-1}

Required: Altitude h =?

The satellite's orbital speed is given by the relation

$$v=\sqrt{\frac{GM_E}{R_E+h}} \Rightarrow h=\frac{GM_E}{v^2}-R_E.$$

Putting values

$$h=\frac{6.67\times10^{-11}\times6\times10^{24}}{(7.6\times10^3)^2}$$

$$h=5.6\times10^5 m=\boxed{560km}$$

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Unit 6

Work and Energy

Q.1: Define work and explain how work is calculated if force is applied at an angle.

Ans. **Work:**

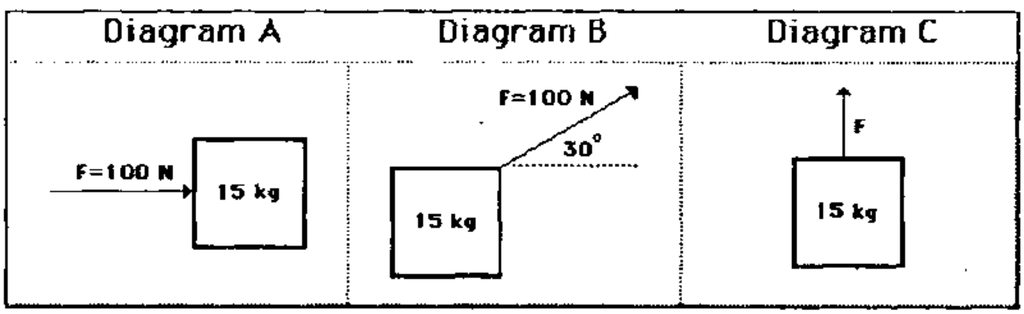
When force is applied on a body and it travels some displacement in the direction of force, we say that work is done. OR

The dot product of force "F" and displacement "S" is called as work.

Mathematically,

$$W = \overline{F}.\vec{S} = FS\cos\theta$$

Whereas, "θ" is the angle between force vector and displacement vector as shown in the figure.



A force "F" is applied at an angle θ due to which the body displaces from one point to another, travelling some displacement S in the direction of force.

Unit and nature:

The SI unit of work is joule. One joule of work is that amount of work when one newton force is applied on a body and its velocity changes by $1ms^{-2}$. Work is a scalar

quantity having no direction as it is the scalar (or dot) product of force F and acceleration a.

Role of angle in work done:

The angle between force and displacement plays a vital role in work done. There are following three possibilities for work due to change in angle.

(a) If both the force applied and displacement travelled are parallel to each other, then work done will be maximum as shown in "Diagram A". Mathematically

$$W = \vec{F}.\vec{S} = FS\cos\theta = FS\cos 0^0 = FS$$

(b) If both the force applied and displacement travelled are perpendicular to each other, then work done will be minimum as shown in "Diagram C". Mathematically

$$W = \vec{F}.\vec{S} = FS\cos\theta = FS\cos 90^0 = 0$$

(c) If the force applied and displacement travelled is at some angle to each other, then work done will be given by the relation

$$W = \vec{F}.\vec{S} = FS\cos\theta$$

Q.2: Define kinetic energy. Derive the expression used for kinetic energy.

Ans. **Kinetic Energy:**

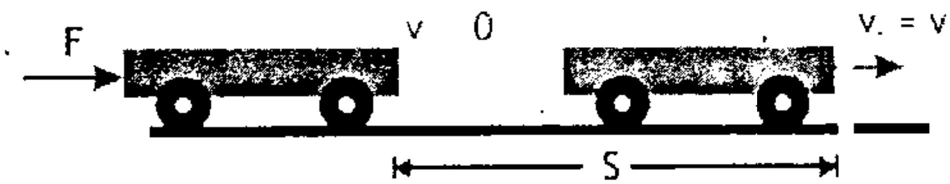
The energy of a body because of its motion is called as kinetic energy. OR Kinetic energy is half of the product of mass of a body and the square of velocity.

Mathematically,

$$E_k = \frac{1}{2}mv^2$$

Unit and Nature:

Kinetic energy is a scalar quantity and having same unit as that of work newton meter called joule.



Consider a cart is at rest. We applied a force F on it and it started motion (with velocity V) in the direction of force. As force is applied and the body started motion so we say that work is done. Mathematically

$$W = F.S = FS\cos 0^0 = FS$$

As we know that $F = ma$

From 3rd equation of motion

$$2as = V_f^2 - V_i^2 \Rightarrow s = \frac{V_f^2 - V_i^2}{2a}$$

Putting value of S in the work formula

$$W = ma(\frac{V_f^2 - V_i^2}{2a}) = m\cancel{a}(\frac{0 - V^2}{2\cancel{a}}) = \frac{1}{2}mV^2$$

This work done W appears as the kinetic energy E_k. Such that

$$W = E_k = \frac{1}{2}mV^2$$

This is the relation for kinetic energy of a body of mass "m" moving with velocity "V".

Q.3: What is potential energy? Prove that the gravitational potential energy of a body of mass m at a height h above the surface of earth is given by mgh.

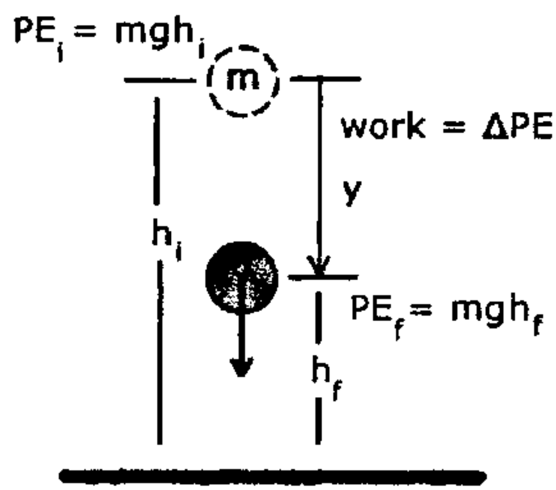
Ans. *The energy of a body because of its position or condition is called as potential energy of the body. OR potential energy is the product of a body's mass, gravitational acceleration and height h from the reference point.*

Mathematically,

$E_p = mgh$

Unit and Nature:

Potential energy is a scalar quantity and having same unit as that of work newton meter called joule.



Proof:

Let us consider a body of mass m, is taken to a height h from the ground. Work is done because force is

applied and the body travelled some distance h. Mathematically,

$$W = F.h = Fh\cos 0^0 = Fh$$

Here the force is acting against gravity so the applied force is equal to the weight of the body given by w = mg.

$$W = mgh$$

This work done is stored in the body in form of gravitational potential energy.

Mathematically,

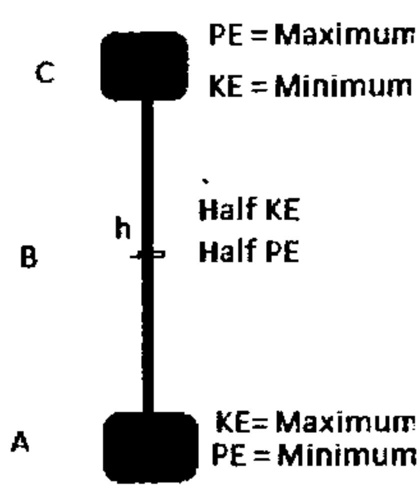
$$W = E_P = mgh$$

This is the mathematical form of gravitational potential energy.

Q.4: State the law of conservation of energy and mass energy conversion relation.

Ans. **Conservation of energy:**

Energy can neither be created nor destroyed but can only be converted from one form to another. The total amount of energy remains constant in any phenomena.



Mathematically

E_T = constant

Or $\Delta E_T = 0$

As shown in the diagram, the total energy at all points (points A, B and C) is constant. It only changes from one form

to another. At point A on ground, the potential energy is minimum whereas kinetic energy is maximum. Moving from point A to point B and then point C, kinetic energy changes to potential. Mathematically,

Increase in potential energy=Decrease in kinetic energy

Loss in kinetic energy = Gain in potential energy

$$\Delta E_k = \Delta E_P$$

$$\Delta E_T = 0$$

Mass- energy conversion relation:

Energy and mass (matter) are inter convertible given by Einstein's mass energy equation that is given by

$$E = mc^2$$

In other words: Energy = mass × the speed of light squared.

Here "C" is speed of light having a constant value $C = 3 \times 10^8 ms^{-1}$.

This equation shows that mass and energy are the same physical entities and can be changed into each other.

Q.5: Explain briefly major sources of energy.

Ans. There are two basic sources of energy known as renewable and non-renewable sources of energy explained briefly as follows.

(A) Renewable source of energy:

Those sources of energy that are replenished (regenerated or refilled) naturally in the course of time are called renewable source of energy. The use of these resources corresponds with the principles of sustainability

because the rate at which we are consuming them does not affect their availability in the long term.

Following are a few types of renewable energy resources.

(i) Solar:

The energy from direct sun light can be used to produce electricity. Sunlight, the fuel required by solar cells, is 100% free and is very eco-friendly. However just like wind energy significant land area is required to produce large amounts of electricity. Pakistan has an estimated 600,000 MW production capacity of solar power as most of the country throughout the year receives sun light.

(ii) Air or Wind:

The kinetic energy of the wind is currently used in many parts of the world to generate electricity. It is eco-friendly source of energy but require very large open space. Pakistan has a capacity of 350,000 MW of wind energy mostly in the coastline built (Gharo Wind Corridor).

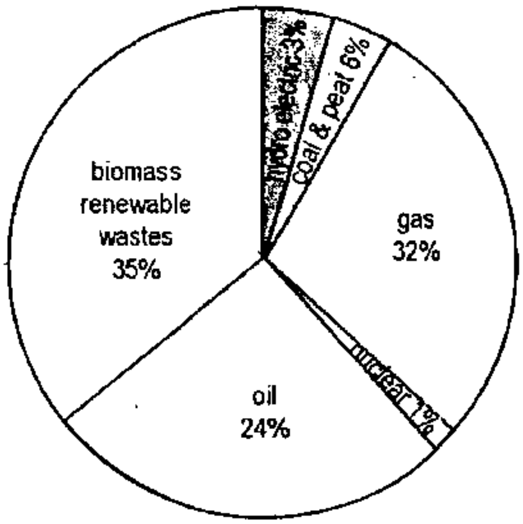
(iii) Nuclear Energy:

Nuclear fission is the process of splitting extremely large atoms (Like Uranium or Polonium) into two or more pieces, which releases an enormous amount of energy in the form of radiation or heat. Currently we are producing about 1000 MW from this.

(iv) Hydel Energy:

Energy generated from water is called as hydel energy. Energy produced in dams is hydel energy. Water is set to fall on large turbines to run producing electrical energy. Turbela dam, Mangla dam and Warsak dam are a few. Pakistan has an estimated efficiency of 60,000MW

electricity to produce from hydel while we only generate a maximum of 8,000MW.



(v) Energy from bio-mass:

"Bio" means life, so bioenergy is energy from living things. The term "biomass" refers to the material from which we get bioenergy. Biomass is produced when the Sun's solar energy is converted into plant matter (carbohydrates) by the process of photosynthesis. Only green plants and photosynthetic algae, containing chlorophyll, are able to use solar energy.

(B) Non-renewable sources of energy:

Those sources of energy that is available to us in limited quantity, or those that are renewed so slowly that the rate at which they are consumed is too fast. This means that their stocks are getting depleted before they can replenish naturally. For example, coal, oil and natural gas are available in limited supplies. Following are a few types of non-renewable energy resources:

(i) Oil:

Oil is the most commonly and most largely used source of energy in the world. Crude oil is refined into

many different energy products such as gasoline, jet fuel and heating oil. Despite the limited reserves of oil in the world it is a preferred source over coal because oil produces more energy than same amount of coal.

(ii) Coal:

Coal is the most abundant fossil fuel in the world, with an estimated reserve of one million metric tons but burning coal results in significant atmospheric pollution.

(iii) Natural gas:

Natural gas is often a by-product of oil; it is mixture of gases most commonly being methane. The use of natural gas is easy to transport once pipelines are in place.

Q.6: Define and explain efficiency.

Ans. Efficiency:

The ratio of useful work to the input fuel is called as efficiency.

Mathematically,

$$Efficiency = \frac{Useful\ amount\ of\ work\ (out)}{input\ work\ (in)}$$

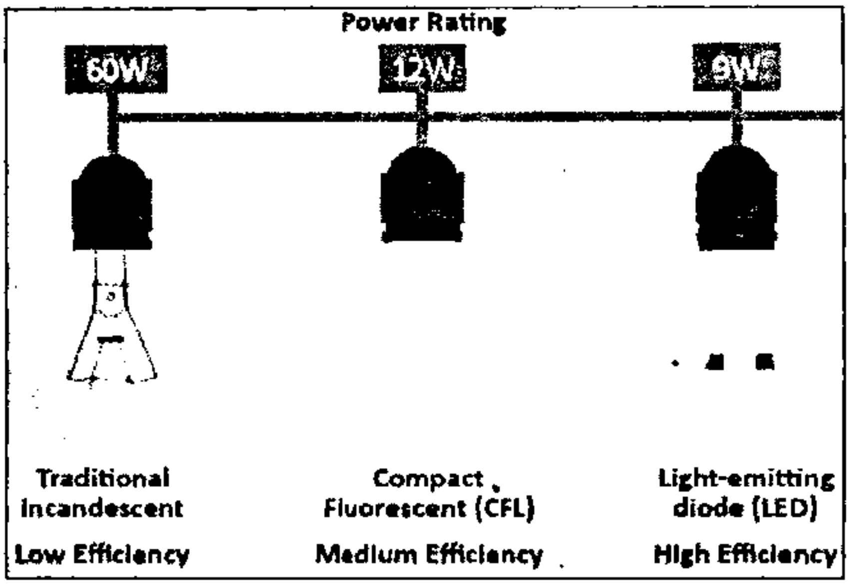
$$Efficiency = \frac{W_{output}}{W_{input}}$$

As work can be represented in-terms of energy so we can also write as

$$Efficiency = \frac{E_{output}}{E_{input}}$$

Usually we estimate the efficiency of a machine (or engine) in percentages given by

$$\%Efficiency = \frac{E_{output}}{E_{input}} \times 100\%$$



If a machine takes 100 joules of energy and do a work of 60 joules then we say that the efficiency of the machine is 60%. Efficiency has no unit as it is the ratio of two same quantities.

Note that the output will always be smaller than the input which means that efficiency can never be 100% or 1. Only for an ideal machine the efficiency can be 100%.

Q.7: Define and explain power.

Ans. **Power:**

The ability/capacity of a body to do work is called as power. OR the time rate of doing work is called as power.

Mathematically,

$$Power = \frac{Work\,done}{Time\,consumed}$$

$$P = \frac{W}{t}$$

Unit and Nature:

The SI unit of power is joules per second called watt. One watt of power is that amount of power when one joule of work is done for one second of time. Power is a scalar quantity having no direction.

Explanation:

Only amount of work is not significant when there is no mention of time. More power means large amount of work is done in a little time interval. For practical purposes we mostly use another unit of power called horse power and kilowatt or megawatt.

$$1hp = 746W$$

$$1kW = 10^3 W$$

$$1MW = 10^6 W$$

Assignments and Examples:

EXAMPLE 6.1:

SUITCASE

A person pulls a suitcase through the airport at 45° angle. The tension in the rope is 20N. How much work does the tension do if the suitcase is pulled 100m?

Solution:

Given:

Tension = Force F = 20 N

Distance S = 100 m

Angle θ = 45°

Required: Work W = ?

By the definition of work

$W = F.S = FS\cos\theta$

Putting values

$W = 20 \times 100\cos 45$

$W = 2{,}000 \times 0.707 = \boxed{1414.21J}$

Because a person pulls the rope, we would say informally that the person does 1414.21 J of work on the suitcase.

ASSIGNMENT 6.1:

TUG OF WAR

During a tug-of-war, team A pulls on team B by applying a force of 1100 N to the rope between them. The rope remains parallel to the ground. How much work does team A do if they pull team B toward them a distance of 2.0 m?

Solution:

Given:

Applied force F = 1100 N

Distance S = 2 m

Angle θ = 0° (As rope is parallel to applied force)

Required: Work =?

By the definition of work

$$W = F.S = FS\cos\theta$$

Putting values

$$W = 1100 \times 2\cos 0^0$$

$$W = 2,200 \times 1 = \boxed{2200J}$$

EXAMPLE 6.2:

BULLET SPEED

A 60.0g bullet is fired from a gun with 3150 J of kinetic energy. Find its velocity.

Solution:

Given:

Mass of bullet m = 60.0 g = 0.06 kg

Kinetic energy of bullet E_k = 3150 J

Required: Velocity of bullet V =?

Kinetic energy is given by

$$E_k = \frac{1}{2}mv^2$$

$$v^2 = \frac{2E_k}{m} \Rightarrow v = \sqrt{\frac{2E_k}{m}}$$

Putting Values

$$v = \sqrt{\frac{2 \times 3150}{0.06}} = \boxed{324ms^{-1}}$$

EXTENSION EXERCISE 6.1:

Hint: $v = \sqrt{\dfrac{2 \times 3150}{800}} = 2.8 ms^{-1}$

This means that 3150 J is a high amount for a bullet but the same amount is low for a car.

ASSIGNMENT 6.2:

BULLET KINETIC ENERGY

A bullet of mass 30 g travels at a speed of $400ms^{-1}$. Calculate its kinetic energy.

Solution:

Given:

Mass of bullet m = 30.0 g = 0.03 kg

Velocity of bullet V = 400 ms^{-1}

Required: Kinetic Energy of bullet E_k =?

Kinetic energy is given by

$$E_k = \frac{1}{2}mv^2$$

Putting Values

$$E_k = \frac{1}{2} \times 0.03 \times 400^2 = \boxed{2400J}$$

EXAMPLE 6.3:

HUMAN JUMP

The maximum height a typical human can jump is about 60cm. By how much does the

gravitational potential energy increase for a 72kg person in such a jump? Where does this energy come from?

Solution:

Given:

Mass of person m = 72 kg

Height h = 60 cm = 0.6 m

Acceleration due to gravity g = 9.8 ms^{-2}

Required: Potential Energy $E_{P,grav}$ =?

Potential energy is given by

$E_{P,grav} = mgh$

Putting values

$E_{P,grav} = 72 \times 9.8 \times 0.6 = \boxed{423.4J}$

This gravitational potential energy comes from elastic potential energy stored in the jumper's tensed muscles.

ASSIGNMENT 6.3:

GAIN IN GRAVITATIONAL POTENTIAL ENERGY

An object of mass 10kg is lifted vertically through a height of 5m at a constant speed. What is the gravitational potential energy gained by the object?

Solution:

Given:

Mass of person m = 10 kg

Height h = 5 m

Acceleration due to gravity $g = 9.8\ ms^{-2}$

Required: Potential Energy $E_{P,grav}$ =?

Potential energy is given by

$E_{P.grav} = mgh$

Putting values

$E_{P.grav} = 10 \times 9.8 \times 5 = \boxed{490J}$

EXAMPLE 6.4:

ENERGY WITHIN US

What is the energy released, when 50 kg person is converted completely into energy?

Solution:

Given:

Mass of the person m = 50 kg

Speed of light $c = 3.0\times10^8$

Required: Energy E =?

By Einstein famous equation of motion

$E = mc^2$

Putting values

$E = 50(3.0 \times 10^8)^2 = \boxed{4.5\times10^{18}J}$

EXTENSION EXERCISE 6.2:

Hint: My mass is 70 kg.

$\text{So}, E = mc^2 \Rightarrow E = 70(3.0\times10^8)^2 = 6.3\times10^{18}J$

ASSIGNMENT 6.4:

ONLY 1g OF ENERGY

How much energy is generated when mass of 1g is completely converted into energy?

Solution:

Given:

Mass of the person m = 1 g = 1×10^{-3} kg

Speed of light c = 3.0×10^{8}

Required: Energy E =?

By Einstein famous equation of motion

$E = mc^2$

Putting values

$E = 1 \times (3.0 \times 10^8)^2 = \boxed{9\times10^{13} J}$

EXAMPLE 6.5:

CRANE POWER

A crane is capable of doing 1.50×10^5 J of work in 10.0 s. What is the power of the crane in watts and hp?

Solution:

Given:

Work W = 1.50×10^5 J

Time t = 10 s

Required: Power P =?

Power is given by the relation, $P = \frac{W}{t}$

Putting values

$$P = \frac{1.5\times10^5}{10} = 1.5 \times 10^4 \text{ watt}$$

Now as 1 hp = 746 watt or 1 watt = $\frac{1}{746}$ hp

$$P = 1.5 \times 10^4 \text{ watt} = \frac{1.5\times10^4}{746} \text{ hp}$$

$$P = \boxed{20\text{hp}}$$

ASSIGNMENT 6.5:

ELECTRIC HEATER

An electric heater is heated at 250 W. Calculate the quantity of heat generated in 10 minutes.

Solution:

Given:

Power of heater P = 250 watt

Time t = 10 min = 10 × 10s = 600s

Required: Heat H =?

Power is given by the relation $P = \frac{W}{t}$

W = P×t

Putting values

$W = 250 \times 600 = 150000\text{J} = 1.5 \times 10^5\text{J}$

This work done is used to generate heat by the heater. So,

$$\boxed{W = H = 1.5\times10^5 J = 150\ kJ}$$

EXERCISE

Multiple Choice Questions

(1) Work done will be zero when the angle between force and displacement is

A. 30° B. 45°

C. 60° D. 90°

(2) 30N force is exerted and the trolley moves a distance of 5 m in the direction of the force, the work done is

A. 6 J B. 25 J

C. 150 J D. 0.17 N

(3) If the speed of a car decreases by half. The kinetic energy change by factor

A. 4 B. 2

C. 1/2 D. 1/4

(4) An object of mass 10 kg is lifted vertically through a height of 5 m. The gravitational potential energy gained by the object is

A. 0.5 J B. 2 J

C. 50 J D. 490 J

(5) If a petrol engine does 20 J of useful work for every 100 J of energy supplied to it, then its efficiency is

A. 80 % B. 60 %

C. 40 % D. 20 %

(6) kWh is unit for

A. Energy B. Power

C. Efficiency D. None

(7) 1 hp =

A. 476 W B. 550 W

C. 746 W D. 1 ft.lb/s

(8) Hira weighing 500 N takes 90 s to reach the top of a hill 18 m high. Her muscle power is

A. 2500 W B. 100 W

C. 32.8 W D. 3.24 W

(9) A machine is able to lift 200 N of concrete slab vertically up to a height of 30 m above the ground in 50 s. The power of the machine is

A. 1.33 W B. 60 W

C. 120 W D. 6000 W

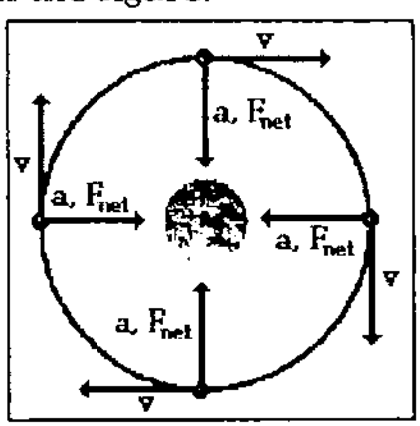
ANSWERS:

1.D	2.C	3.D	4.D	5.D	6.A	7.C	8.B	9.C	

CONCEPTUAL QUESTIONS

(1) Can a centripetal force ever do work on an object? Explain.

Ans. No, a centripetal force cannot do work on an object because force and displacement (or velocity) are perpendicular (θ=90°) to each other at every point as shown in the figure.



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Explanation:

It is clearly evident from the figure that force and velocity (and hence displacement) are perpendicular ($\theta = 90°$) to each other. Mathematically

$$W = F.S = FS\cos\theta = FS\cos 90^0$$

As $\cos 90^0 = 0$. So, $W = 0$.

(2) What happens to the kinetic energy of a bullet when it penetrates into a sand bag?

Ans. Kinetic energy goes to zero, because the bullet stops when it's embedded in the target.

Explanation:

Here conservation of energy principle is involved which says energy can neither be created nor destroyed but can only be converted from one form to another.

Kinetic energy of bullet is converted into some other kinds of energy according to the conservation of energy law. Some of these other forms include heat from friction, sound (thump), target motion (conservation of momentum), structural deformation (strain) and shrapnel kinetic energy.

(3) A meteor enters into earth's atmosphere and burns. What happens to its Kinetic energy?

Ans. The kinetic energy of the meteor when it enters into the earth's atmosphere is converted to other forms of energy.

Explanation:

A meteor has both potential and kinetic energy before entering the atmosphere of the Earth. As it enters

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and falls towards the surface of the Earth, frictional heating occurs, caused by collision with the molecules in the atmosphere which reduces its velocity. Hence the kinetic energy decreases, which is converted to heat energy.

(4) Two bullets are fired at the same time with the same kinetic energy. If one bullet has twice the mass of the other, which has the greater speed and by what factor? Which can do the most work?

Ans. The bullet having low mass will have high speed and both the bullets will do the same amount of work.

<u>Explanation:</u>

The velocity of a particle having mass "m" and kinetic energy E_k is given by

$$v = \sqrt{\frac{2E_k}{m}}$$

Smaller the mass, greater the velocity will be and vice versa. Doubling the mass will decrease the velocity by a factor of square root of 2, i.e. will be

$$V_{lighter} = \sqrt{2}V_{heavier}$$

Whereas, there will be no difference in the work they can do because both have same kinetic energy.

(5) Can an object have different amounts of gravitational potential energy if it remains at the same elevation?

Ans. Yes, an object can have different amounts of gravitational potential energy if it remains at the same elevation.

Explanation:

Since gravitational potential energy is measured relative to a point which could change. That point could be the ground level, the basement level, or any other arbitrary point.

For example, you are travelling in an aeroplane. If you take the floor of the aeroplane to be your reference point, then your potential energy is zero. But if you consider your reference point as surface of earth, then you have a potential energy given by $E_P = mgh$.

Whereas m is your mass and h is height.

(6) Why do roads, leading to the top of a mountain wind, back and forth?

Ans. When the roads leading up a mountain wind back and forth, the angle of inclination of the road is less than that of a road going straight up the mountain.

Mathematically ,

$W = F.S = FS\cos\theta$

This reduces the force necessary to drive the car up the road and the required power output of the engine as well. The length of road is increased, however, so the total work that must be done to reach the top of the mountain remains the same (or may be larger if frictional forces are taken into account).

(7) Which would have a greater effect on the kinetic energy of an object, doubling the mass or doubling the velocity?

Ans. Doubling the velocity will affect greatly the kinetic energy of an object than doubling the mass.

Explanation:

The kinetic energy of an object is given by

$$E_k = \frac{1}{2}mv^2$$

$E_k \propto m$ and $E_k \propto v^2$

Kinetic energy is directly proportional to the mass of the object. It means doubling mass will only increase kinetic energy two times.

Whereas, kinetic energy is directly proportional to the square of the velocity, which means doubling the velocity of an object the kinetic energy will increase four times.

(8) If the speed of a particle triples, by what factor does its kinetic energy increase?

Ans. The kinetic energy will increase nine times if the speed of a particle triples.

Explanation:

The Kinetic energy of a body having mass "m" moving with velocity "v" is given by

$$E_k = \frac{1}{2}mv^2$$

Let new velocity be V′ = 3V, then new kinetic energy be E_k' and will be

$$E_k' = \frac{1}{2}m(3v)^2 = \frac{1}{2}9mv^2$$

$$E_k' = 9(\frac{1}{2}mv^2) = 9E_k$$

(9) The motor of a crane uses power P to lift a steel beam. By what factor must the motor's power increase to lift the beam twice as high in half the time?

Ans. The motor power must increase four (4) times to lift the same beam twice as high in half the time.

Explanation:

The mathematical relation for power is given by

$$P = \frac{W}{t} \qquad \text{As } W = F.d$$

$$P = \frac{F.d}{t} \text{...........}(1)$$

Now to find new power (P′) for new height (d′=2d) and new time ($t' = \frac{1}{2}t$)

$$P' = \frac{F.2d}{\frac{1}{2}t} = 4\left(\frac{F.d}{t}\right) = \boxed{4P}$$

So, the power must increase four times.

NUMERICAL QUESTIONS

(1) Determine the work done in each of the following cases:

a) Kicking a soccer ball forward with a force of 40N over a distance of 15cm

b) Lifting a 50kg barbell straight up 1.95m

Solution:

Given:

(a) Force F = 40 N

Distance S = 15 cm = 0.15 m

Required: W_1 =?

(b) Mass m = 50 kg

Distance S = 1.95 m.

Required: W_1 =?

The mathematical relation for work is given by

W = FS

(a) Putting values in above equation

$W_1 = FS = 40 \times 0.15 = \boxed{6J}$

(b) As we know that weight is given by w=F=mg, so,

$W_2 = FS = mgS$

Putting values

$W_2 = 50 \times 9.8 \times 1.95 = \boxed{955.5J}$

(2) Calculate the velocity of a 1.2kg falling star (meteorite) with 5.5×10^8 J of energy.

Solution:

Given:

Mass of falling start=1.2kg

Energy released $E = 5.5 \times 10^8$ J

Required: Velocity of falling star V =?

As the falling star is in motion so, its energy and velocity can be given by

$$E_k = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2E_k}{m}}$$

Putting values

$$v = \sqrt{\frac{2 \times 5.5 \times 10^8}{1.2}} = \boxed{3.02 \times 10^4 ms^{-1}}$$

(3) Calculate the gravitational potential energy of a 2000 kg piano.

a) resting on the floor b) with respect to the basement floor, 1.9 m below.

Solution:

Given:

Mass of piano m = 2000 kg

Acceleration due to gravity g = 9.8 ms^{-2}

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Required: Potential energy E_P =?

(a) Resting on the floor h = 0 m

(b) Basement floor h = 1.9 m.

The potential energy of an object is given by

$E_P = mgh$

(a) Putting values

$E_P = 2000 \times 9.8 \times 0 = \boxed{0J}$

(b) Putting values

$E_P = 2000 \times 9.8 \times 1.9 = 37{,}240J = \boxed{3.7 \times 10^4 J}$

(4) An elevator weighing 5000N is raised to a height of 15.0m in 10.0s, how much power is developed?

Solution:

Given:

Weight of elevator w = 5000 N

Height h = 15 m

Time t = 10 s

Required: Power developed P =?

The power is given by the relation

$$P = \frac{W}{t} = \frac{F.S}{t} = \frac{w.h}{t}$$

Putting values

$$P = \frac{5000 \times 15}{10} = 7500W = \boxed{7.5KW}$$

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(5) What power is required for a ski-hill chair lift that transports 500 people (average mass 65kg) per hour to an increased elevation of 1200m?

<u>Solution:</u>

Given:

Mass of chair lift m = 500 × 65kg = 32,500kg

Weight of the left w = mg

w = 32,500 × 9.8 = 318,500 N

Height h = 1200 m

Time t = 1 h = 1 × 60 × 60s = 3600s

Required: Power P =?

The power is given by the relation

$$P = \frac{W}{t} = \frac{F.S}{t} = \frac{w.h}{t}$$

Putting values

$$P = \frac{318,500 \times 1200}{3600} = 106,166.67W = \boxed{106.2KW}$$

(6) How long will it take a 2750W motor to lift a 385kg sofa set to a sixth-storey window 16.0m above?

<u>Solution:</u>

Given:

Power of motor P = 2750 W

Mass of sofa m = 385 kg

Height h = 16.0 m

Required: Time t =?

The power is given by the relation

$$P = \frac{W}{t} \Rightarrow t = \frac{W}{P} = \frac{F.h}{P} = \frac{mgh}{P}$$

$$t = \frac{mgh}{P}$$

Putting Values

$$t = \frac{385 \times 9.8 \times 16}{2750} = 22$$

$$\boxed{t = 22s}$$

(7) How much work can a 2.0-hp motor do in 1.0 h?

Solution:

Given:

Power of motor p = 2.0 hp

p = 2.0 × 746 = 1492 W

Time t = 1.0 h = 1.0 × 3600 s = 3600 s

Required: Work W =?

The power is given by the relation

$$P = \frac{W}{t} \Rightarrow W = P \times t$$

Putting values

W = 1492 × 3600 = 5,371,200

$$\boxed{W = 5.37 \times 10^6 J}$$

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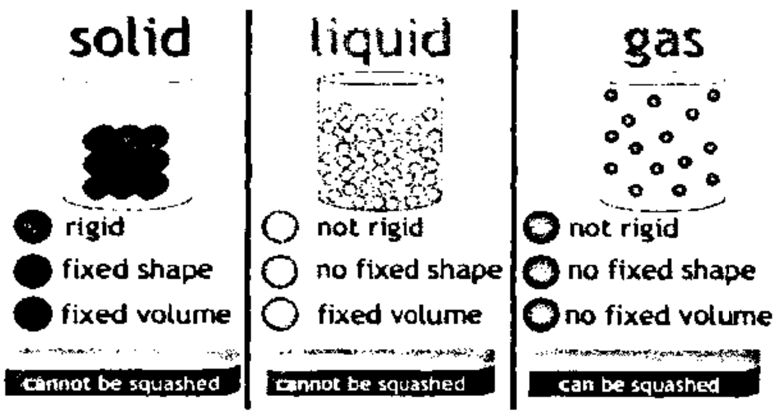
Unit 7

Properties of Matter

Q.1: Using kinetic molecular model of matter, explain three states of matter.

Ans. Matter has three states solids, liquids and gases. These three states of matter are explained on the basis of Kinetic Molecular Theory. The explanation is as under:



(A) Solids:

Solids have following properties.

1. Solids are made up of molecules which are arranged closely in a fixed pattern.
2. Molecules in solids vibrate about their mean positions.
3. The attractive forces between the molecules are strong.
4. A solid has a fixed shape.

(B) Liquids:

Liquids have following properties.

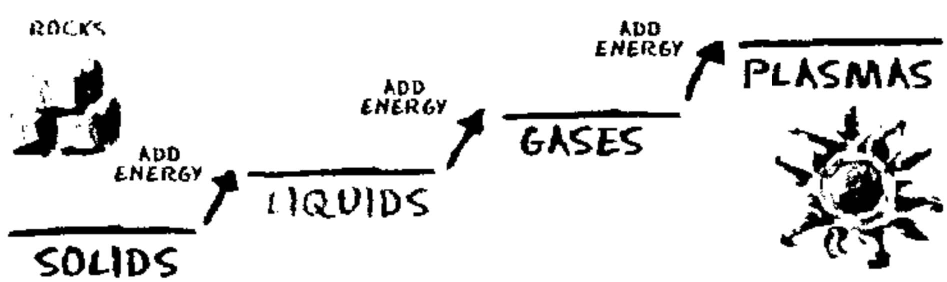
1. Liquids are also made up of molecules which are close together.
2. The pattern of molecules is not fixed and does not extend far. The molecules in a pattern keep changing their position.
3. Molecules are able to move about, which means that a liquid is able to change its shape and can adopt the shape of the container.
4. The attractive forces between the molecules of liquid are less than the solid.

(C) Gases:

Gases have following properties.

1. A gas is made up of molecules which are in constant random motion.
2. The distance between molecules is larger as compared to the size of the molecules.
3. The molecules are constantly colliding elastically with each other and with the walls of the container.
4. Forces between molecules are negligible, except during collisions.

Liquids and gases are collectively called as fluids because both have the ability to flow.



THE STATE OF MATTER CHANGES AS YOU ADD MORE ENERGY

Q.2: Define and explain density and pressure.

Ans. **Density:**

The mass per unit volume of a substance is called as density.

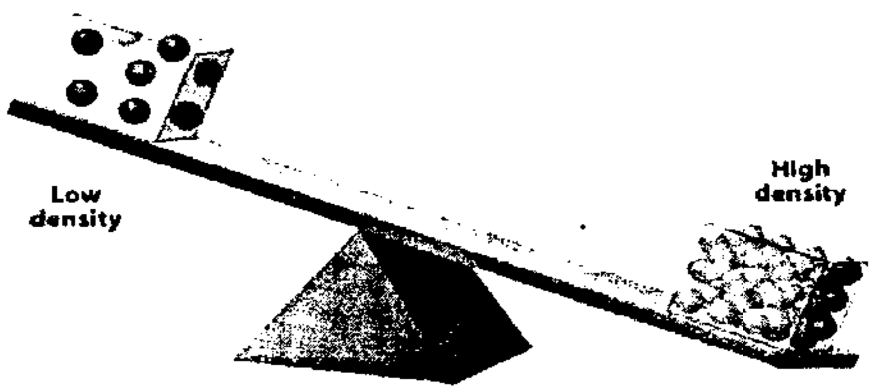
Mathematically,

$$\rho = \frac{m}{V}$$

Whereas, ρ is density, m is mass of the substance (material) and V is volume occupied by that mass.

Explanation:

Let us take two boxes of same volume. Fill one box with rocks while the other with tennis balls. The one filled with rocks will weight heavy than the other as shown in the figure.



It is because for same amount of volume more mass of rocks is there than of tennis balls.

Unit and nature:

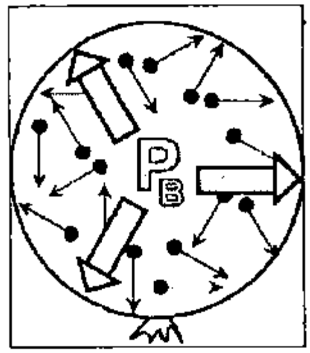
The unit of density is kgm^{-3} and is a scalar quantity having no direction.

Pressure:

The force per unit area applied perpendicular on a surface is called as pressure.

Mathematically,

$$P = \frac{F}{A}$$



Whereas P is pressure, F is applied force and A is area of the surface upon which pressure exerts.

Explanation:

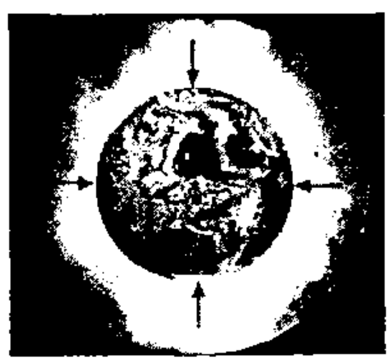
As shown in the diagram, gas particles inside balloon exert force on the walls of the balloon. This force per unit area is called as pressure.

Unit and nature:

Pressure is a scalar quantity having unit of Nm^{-2}.

Q.3: What is atmospheric pressure? How is it measured by using a mercury barometer? Also describe how weather changes with atmospheric pressure?

Ans. **Atmospheric pressure:**



The pressure that atmosphere exerts is called as atmospheric pressure.

Explanation:

In air we have different gases. These gases exert force on the surface of earth (due to the

weight of the gas particles or we can say due to the gravitational attractive force between earth and gas particles) which is called atmospheric pressure.

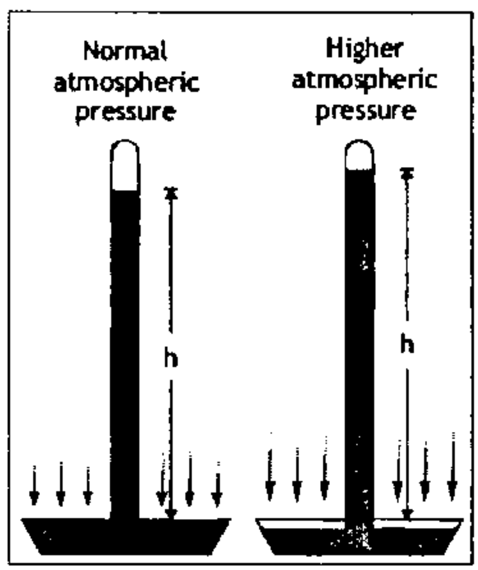
As shown in the figure the atmosphere is exerting a force on the surface of earth from all directions.

Its value is 101325 Nm^{-2} = 1 atm at sea level.

The air around us exerts a force in all directions and is opposed by an equal pressure inside our body Thus, we are generally unaware of it. However, when the air is pumped out of a sealed can, atmospheric pressure produces an inward force that is unopposed. The resulting collapse of the can illustrates the pressure that is all around us.

Measurement by using mercury barometer:

A long tube that is open at one end and closed at the other is filled with mercury and then inverted into a dish of mercury. Once the tube is inverted, the mercury does not empty into the bowl. Instead, the atmosphere exerts a pressure on the mercury in the bowl. This atmospheric pressure pushes the mercury in the tube to some height 'h' above the bowl. In this way, the force exerted on the bowl of mercury by the atmosphere is equal to the weight of the column of mercury in the tube. Any change in the height 'h' of the column of mercury means that the atmosphere's pressure has changed. At sea level, the atmosphere will push down



on a pool of mercury and make it rise up in a tube to a height of approximately 760mm.

Change in weather by atmospheric pressure:

Barometers kept in the same place at the same height above sea level show some variation in atmospheric pressure from day to day. These pressure variations are shown on weather maps. The lines in the map joining all those places with the same atmospheric pressure are called isobars. The unit for pressure used in weather maps is the millibar (mbar)

1000 mbar = 1 bar

1 bar = 100 kPa, nearly equal to normal atmospheric pressure.

Q.4: State Pascal's principle and explain with example?

Ans. Pascal Principle:

This principle states that in a fluid at rest in a closed container, a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container.

Explanation:

For example, in the figure below, P_3 would be the highest value of the three pressure readings, because it has the highest level of fluid above it. If the below container had an increase in overall pressure, that same added pressure would affect each of the gauges (and the liquid throughout) the same.

For example, P_1, P_2, P_3 were originally 1, 3, 5 units of pressure, and 5 units of pressure were added to the system the new readings would be 6, 8 and 10.

Mathematically,

$P_1 = P_2 = P_3$

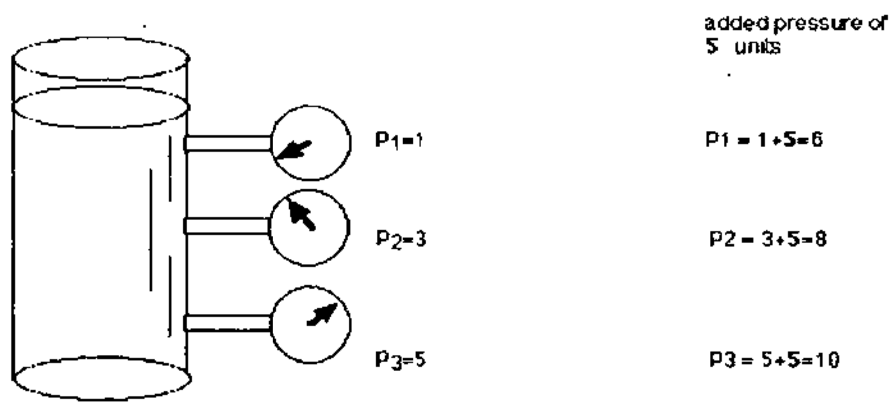
Let us consider any two points then

$P_1 = P_2$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\Rightarrow F_2 = \frac{A_2}{A_1} F_1$$

Depending on the ratio $\frac{A_2}{A_1}$ the force F can be as large as possible.



Q.5: How pressure varies with depth in liquids? Explain.

Ans. *Pressure varies with depth in liquids because the further down you go, the greater the weight of liquid above.*

Explanation:

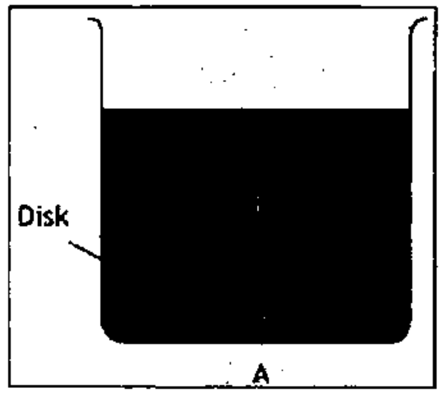
The liquid is incompressible therefore the pressure increases directly below the surface of the liquid. In

figure a disc is placed at the bottom of a tank in fluid. The force F acting on the disc is the weight W of the cylindrical column of liquid of mass m.

$$F = W = mg$$

For the fluid of density ρ, the mass m of the fluid above the disk, with volume V is

$$\rho = \frac{m}{V} \Rightarrow m = \rho V$$



Since the fluid forms a cylindrical volume V shown by dotted lines in the figure which has height h and area of cross section A. So, V = Ah.

Putting in above equation

$$m = \rho Ah$$

Putting it in equation 1

$$F = \rho Ahg$$

From the definition of pressure

$$P = \frac{F}{A} = \frac{\rho \cancel{A} hg}{\cancel{A}} \Rightarrow P = \rho gh$$

$$\rho \propto h$$

For the same fluid increasing depth of the fluid, pressure will increase as shown in the figure the water spurts out fastest and furthest from the lowest hole (large h).

Q.6: What is meant by buoyant force or up thrust in fluids?

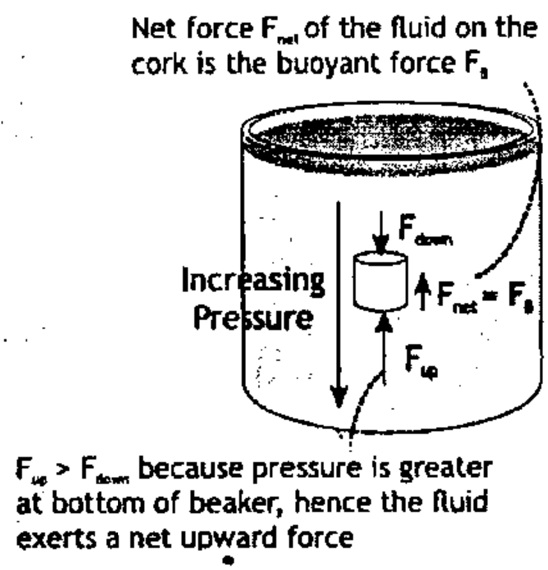
Ans. **<u>Buoyant force:</u>**

When an object is placed in a fluid, the fluid exerts an upward force we call the buoyant force.

Explanation:

The buoyant force comes from the pressure exerted on the object by the fluid. Because the pressure increases as the depth increases, the pressure on the bottom of an object is always larger than the force on the top - hence the net upward force.

If you try to push a piece of cork underwater, you feel the effects of the buoyant force pushing the cork back up. It takes rather a large force to hold such an object completely underwater; the instant you let it go, the object pops up to the surface.



Q.7: State and explain Archimedes principle.

Ans. This principle states that "any object completely or partially submerged in a fluid (gas or liquid) at rest is acted upon by an upward or buoyant force. The magnitude of this force is equal to the weight of the fluid displaced by the object.

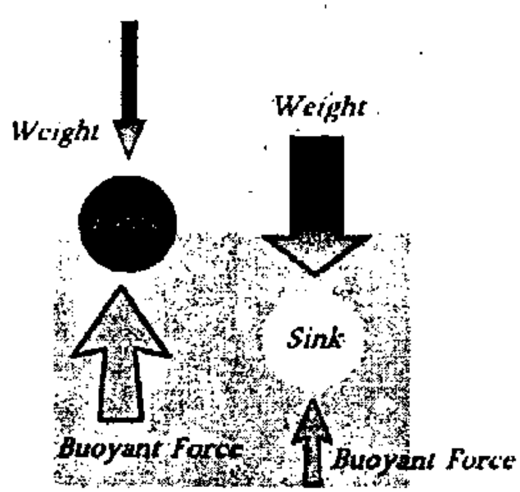
Mathematically,

$$F_{buoyant} = W_{displaced,fluid} = m_f g$$

Explanation:

According to Archimedes principle, every object experiences a buoyant force, whether it floats or sinks depends on the object's density relative to the fluid.

If the weight of the water displaced is less than the weight of the object, the object will sink otherwise the object will float, with the weight of the water displaced equal to the weight of the object as shown in above figure. A piece of cork will float over water surface while a small needle will sink.



Whether an object will float or sink depends on the net force acting on it. This net force can be calculated as follows:

$$F_{net} = F_B - W_{object}$$

$$F_{net} = m_f g - m_o g$$

Whereas, m_f is mass of the fluid displaced and m_o is mass of the object that is inserted in water. As we know that 'm = ρV', so the expression can be rewritten as follows:

$$F_{net} = \rho_f V_f g - \rho_o V_o g = (\rho_f V_f - \rho_o V_o) g$$

This is the mathematical relation for the net force acting on body inside a fluid.

A simple relationship between the weight 'W' of a submerged object of mass m_o and density ρ_o and the

buoyant force 'F_B' on the object by fluid displaced of mass m_f and density ρ_f can be found by considering their ratio as follows:

$$\frac{W}{F_B} = \frac{m_o \cancel{g}}{m_f \cancel{g}} \Rightarrow \frac{W}{F_B} = \frac{m_o}{m_f}$$

For submerged object equal volume is displaced therefore $V_o = V_f = V$

Therefore, $m_o = \rho_o V$ and $m_f = \rho_f V$

$$\frac{W}{F_B} = \frac{\rho_o \cancel{V}}{\rho_f \cancel{V}} \text{ or } \frac{W}{F_B} = \frac{\rho_o}{\rho_f}$$

Q.8: What is elasticity? Explain.

Ans. <u>Elasticity:</u>

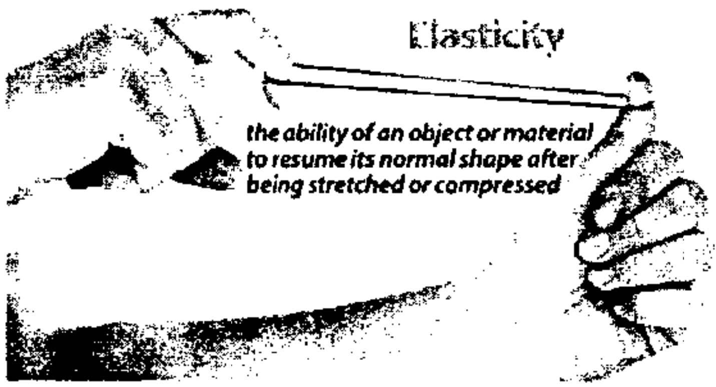
The property of solid materials to return to their original shape and size after the forces deforming them have been removed is called elasticity.

<u>Explanation:</u>

Most solid materials exhibit elastic behaviour, but there is a limit to the magnitude of the force and the accompanying deformation within which elastic recovery is possible for any given material called the elastic limit. The elastic limit depends markedly on the type of solid considered. For example, a steel bar or wire can be extended elastically only about 1 percent of its original length, while for strips of certain rubberlike materials, elastic extensions of up to 1,000 percent can be achieved.

Not all materials return to their original shapes when deforming force acting on it is removed. Materials that do not return to their original shapes after being

distorted are said to be inelastic. Examples of inelastic materials are plasticine, clay and dough.



Q.9: Define and explain Stress, Strain and Young's modulus.

Ans. **Stress:**

The force per unit area applied on a body to deform its shape is called as stress.

Mathematically,

$$Stress = \frac{Force}{Area} = \frac{F}{A}$$

Unit and nature:

The unit for stress is Nm^{-2} or pascal. Stress is a scalar quantity having no direction.

Strain:

The deformation produced in a body due to stress is called as strain. OR The change in length per unit initial length is called as strain.

Mathematically,

$$Strain = \frac{Change\,in\,length}{Initial\ length} = \frac{\Delta l}{L} = \frac{x}{L}$$

Unit and nature:

Since strain is the ratio of two lengths, it does not have a unit. It is a scalar quantity having no direction

Young's Modulus:

The ratio between stress and strain is called as young's modulus.

Mathematically,

$$\text{Young's modulus} = \frac{Stress}{Strain}$$

$$Y = \frac{F/A}{x/L} = \frac{F \times L}{A \times x}$$

Explanation:

The strain produced in a stretched wire is proportional to the stress within the limit of proportionality. Within this limit, the ratio is a constant whose value depends on the material of the wire.

Mathematically,

Stress $\propto$ Strain

Stress = Constant × Strain

$$\text{Constant} = \frac{Stress}{Strain}$$

$$Y = \frac{F/A}{x/L} = \frac{F \times L}{A \times x}$$

This constant of proportionality is called as Young's modulus represented by Y. It has the same unit as that of the stress i.e. Nm^{-2} or pascal because strain is a unitless quantity.

Young Modulus for different materials is given in the below table.

Material	E/x 10^9 Pa
Diamond	1200
Titanium carbide	345
Steel	210
Copper	130
Brass	100
Glass	80
Oak	12
Rubber band	0.02

Q.10: State and explain Hooke's law.

Ans. <u>Hooke's Law:</u>

Within certain limits, the restoring force on an elastic object such as a metal spring is directly proportional to the extension of the spring. This is known as Hooke's law.

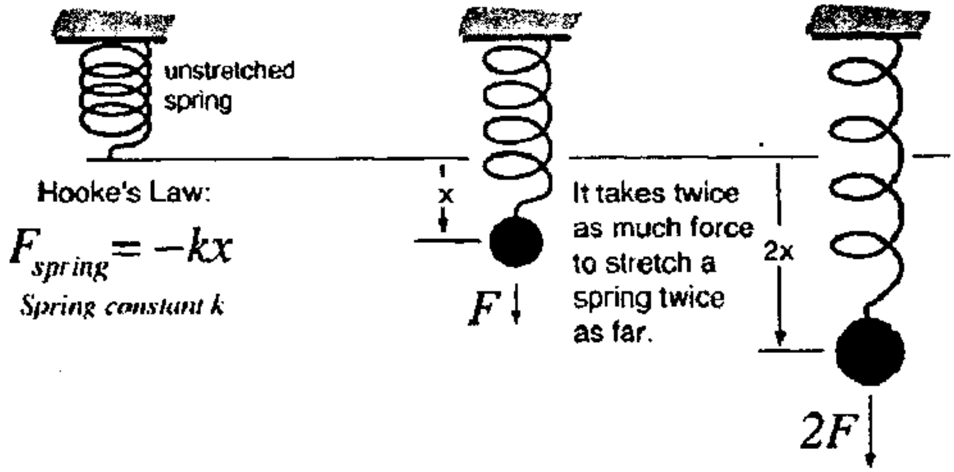
Mathematically,

$$F_{spring} \propto -x$$

$$F_{spring} = -kx$$

Whereas, "k" is force constant and x is extension in spring as shown in the diagram. The negative sign shows that force is directed against displacement.

As shown in the figure, increasing the stretching of the spring a larger force is required.



Examples and Assignments:

EXAMPLE 7.1:

DENSITY OF METAL

A metal piece has length 0.3m, width 0.2m and height 0.1m. If its mass is 47.4kg. Calculate its density.

Solution:

Given:

Length of metal piece L = 0.3 m

Breadth of metal piece B = 0.2 m

Height of metal piece H = 0.1 m

Mass of metal piece m = 47.7 kg

Required: Density of metal =?

Hence Volume, V = L × B × H = 0.3 × 0.2 × 0.1

$=0.006m^3$

The relation for density is

$$\rho = \frac{m}{V} = \frac{47.4}{0.006} = \boxed{7900kgm^{-3}}$$

ASSIGNMENT 7.1:

DENSITY OF DIAMOND:

A diamond has a volume of 0.00002 m^3, its mass is measured as 0.072 kg. Calculate its density.

Solution:

Given:

Volume of diamond V = 0.00002 m^3

Mass of diamond m = 0.072 kg

Required: Density of diamond ρ = ?

The relation for density is

$$\rho = \frac{m}{V} = \frac{0.72}{0.0002} = \boxed{3600 kgm^{-3}}$$

EXAMPLE 7.2:

WEIGHT AS PRESSURE ON GROUND:

A 40kg girl's two feet cover an area of 500cm^2 (a) Determine the pressure exerted by the two feet on the ground. (b) If the girl stands on one foot, what will be the pressure under that foot?

Solution:

Given:

Mass of girl m = 40 kg.

So, her weight will be w = mg

$= 40 \times 9.8 = 392N$

Area she covers A = 500cm^2

$= 500 \times 10^{-4} m^2 = 0.05 m^2$

Required: (a) $P_1 = ?$

(b) $P_2 = ?$

(a) From the definition of pressure

$$P = \frac{F}{A} = \frac{w}{A}$$

Putting values

$$P = \frac{392}{0.05} = 7840 Nm^{-2} = 7.8 \times 10^3 Pa = 7.8 kPa$$

(b) When the girl stands on one foot, her weight is same but area will become half and we will have the value of pressure double.

Mathematically,

$$P = \frac{392}{0.025} = 15680 Nm^{-2}$$

$$P = 15.68 \times 10^3 Pa = \boxed{15.68 kPa}$$

EXTENSION EXERCISE 7.1: Hint:

Then area will reduce to $0.0001 m^2$ and the pressure she exerts on ground will be $P = \frac{392}{0.0001} = 3,920,0000 Nm^{-2}$ $= 3,920 \times 10^3 Pa = 3920 kPa$

ASSIGNMENT 7.2:

CONCRETE BLOCK

A block of concrete weighs 900 N and its base is a square of side 3 m. What pressure does the block exert on the ground?

Solution:

Given:

Weight of Block w = 900 N

Length of square side L = 3 m.

So, Area will be $A = L \times L = 3 \times 3 = 9m^2$

Required: Pressure P =?

The pressure exerted by a body on Area A is given by

$$P = \frac{F}{A} = \frac{w}{A}$$

Putting values

$$P = \frac{900}{9} = 100Nm^{-2} = \boxed{100Pa}$$

EXAMPLE 7.3:

<u>LIMITS ON SUBMARINE DEPTH</u>

A submarine is constructed so that it can safely withstand a pressure of 1.6 × 10^7 Pa. How deep may this submarine descend in the ocean if the average density of seawater is 1025 kg/m^3?

<u>Solution:</u>

Given:

Pressure P = 1.6 × 10^7 Pa

Density of sea-water $\rho = 1025kgm^{-3}$

Acceleration due to gravity $g = 9.8ms^{-2}$

Required: Depth = height h =?

The maximum depth a submarine can go down can be measured by equation

$$P = \rho g h \Rightarrow h = \frac{P}{\rho g}$$

Putting values

$$h = \frac{1.6 \times 10^7}{1025 \times 9.8} = 1600m = \boxed{1.6km}$$

ASSIGNMENT 7.3:

PRESSURE AT 100m DEPTH OF WATER:

What is the pressure at a depth of 100 m below the surface of water?

Solution:

Given:

Depth = height h = 100 m

Density of sea-water $\rho = 1025kgm^{-3}$

Acceleration due to gravity $g = 9.8ms^{-2}$

Required: Pressure P =?

The pressure can be measured by equation

$$P = \rho g h$$

Putting values

$$P = 1025 \times 9.8 \times 100 = 1.004 \times 10^6 Pa = \boxed{1004kPa}$$

EXAMPLE 7.4:

IS CROWN MADE OF PURE GOLD?

A girl purchases a "gold" crown at a flea market. After she gets home, she hangs the crown

from a scale and finds its weight to be 7.84N. She then weighs the crown while it is immersed in water, and the scale reads 6.86N. Is the crown made of pure gold?

Solution:

Given:

Weight in air $w_{air} = 7.84N$

Weight in water $w_{water} = 6.86N$

Density of water $\rho_{water} = 1.00 \times 10^3 kgm^{-3}$

Required: Density of crown $\rho_{crown} = ?$

Because the object is completely submerged, the buoyant force 'F_B' on the object can be calculated as

$$F_B = w_{air} - w_{water}$$

Putting values

$$F_B = 7.84 - 6.86 = 0.98N$$

The relationship between the weight 'W' and the buoyant force 'F_B' is

$$\frac{w_{air}}{F_B} = \frac{\rho_{crown}}{\rho_{water}}$$

$$\Rightarrow \rho_{crown} = \frac{w_{air}}{F_B} \times \rho_{water}$$

Putting values

$$\Rightarrow \rho_{crown} = \frac{7.84}{0.98} \times 1.00 \times 10^3 = \boxed{8 \times 10^3 kgm^{-3}}$$

As the density of gold are 19.3×10^3kg/m^3. Because 8.0×10^3kg/m^3 are quite less than 19.3×10^3 kg/m^3, the crown cannot be of pure gold.

ASSIGNMENT 7.4:

DENSITY OF ROCK:

A geologist finds that a Moon rock whose weight is 90.9 N has an apparent weight of 60.6 N when submerged in water. What is the density of the rock?

Solution:

Given:

Weight in air $w_{air} = 90.9N$

Weight in water $w_{water} = 60.6N$

Density of water $\rho_{water} = 1.00 \times 10^3 kgm^{-3}$

Required: Density of Rock $\rho_{rock} = ?$

Because the object is completely submerged, the buoyant force 'F_B' on the object can be calculated as

$$F_B = w_{air} - w_{water}$$

Putting values

$$F_B = 7.84 - 6.86 = 0.98N$$

The relationship between the weight 'W' and the buoyant force 'F_B' is

$$F_B = w_{air} - w_{water}$$

Putting values

$$F_B = 90.9 - 60.6 = 30.3N$$

The relationship between the weight 'W' and the buoyant force 'F_B' is

$$\frac{w_{air}}{F_B} = \frac{\rho_{rock}}{\rho_{water}}$$

$$\Rightarrow \rho_{rock} = \frac{w_{air}}{F_B} \times \rho_{water}$$

Putting values

$$\Rightarrow \rho_{rock} = \frac{90.9}{30.3} \times 1.00 \times 10^3 = \boxed{3 \times 10^3 kgm^{-3}}$$

EXAMPLE 7.5:

YOUNG'S MODULUS

A wire of length 5.0m and area of 0.03m^2 is stretched 0.15m within elastic limit, by hanging weight of 270N. Calculate stress, strain and Young's modulus of material of wire.

Solution:

Given:

Length of wire L = 5.0 m

Area of wire A = 0.03m^2

Extension x = 0.15 m

Weight = Force 270 N

Required: (a) Stress =?

(b) Strain =?

(c) Young's Modulus Y =?

(a) By definition of stress

$$Stress = \frac{F}{A} = \frac{270}{0.03} = 9{,}000 Nm^{-2} = \boxed{9 \times 10^3 Nm^{-2}}$$

(b) By definition of strain

$$Strain = \frac{X}{L} = \frac{0.15}{5.0} = \boxed{0.03 Nm^{-2}}$$

(c) By definition of Young's modulus

$$Y = \frac{stress}{strain} = \frac{9,000}{0.03} = \boxed{3.0 \times 10^5 Nm^{-2}}$$

ASSIGNMENT 7.5:

WIRE STRETCHED

An elastic wire of length 2m and cross-sectional area 0.02m² is stretched 0.10 m by a 300N weight. Calculate the Young modulus of the material.

Solution:

Given:

Length of wire L = 2.0 m

Area of wire A = $0.02m^2$

Extension x = 0.10 m

Weight = Force 300 N

Required: Young's Modulus Y =?

By definition of Young's modulus

$$Y = \frac{stress}{strain}$$

As we know that stress is $Stress = \frac{F}{A}$ and strain is $Starin = \frac{X}{L}$. Putting in above equation

$$Y = \frac{F \times L}{A \times X}$$

Putting values

$$Y = \frac{300 \times 2.0}{0.02 \times 0.10} = 300,00 Nm^{-2} = \boxed{3 \times 10^5 Nm^{-2}}$$

EXERCISE

Multiple Choice Question:

(1) A container having volume of 6 m^3 is full with a liquid, having density of 30 kg m^{-3}. The mass of the liquid is

A. 180 kg B. 24 kg
C. 5 kg D. 0.2 kg

(2) Liquids and gases are collectively categorized as

A. Liquids B. Pascals
C. Fluids D. None

(3) Which of the following cannot be used to measure pressure?

A. Atm B. Pa
C. Bar D. kg m^{-3}

(4) Pressure at depth in fluid

A. increases B. Decreases
C. stays the same D. none

(5) The unit used for pressure in weather maps is

A. Atm B. Pa
C. Bar D. N m^{-2}

(6) A rock weighs 25.7 N in air and 21.8 N in water. What is the buoyant force of the water?

A. 4.1 N B. 3.9 N
C. 1.18 N D. 0.84 N

(7) Which of the following objects, submerged in water, experiences the largest magnitude of the buoyant force?

A. 1 kg helium balloon B. 1 kg of wood
C. 1 kg of iron D all the same.

(8) The unit of strain is
A. kg m^{-3} B. Pa
C. N m^{-2} D. none

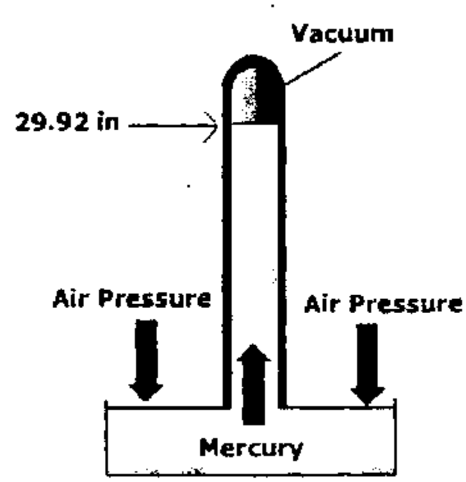
(9) Young modulus is measured in units of
A. kg m^{-3} B. Pa
C. N D. none

ANSWERS:

1.A	2.C	3.D	4.A	5.A	6.B	7.D	8.D	9.B	

CONCEPTUAL QUESTIONS

(1) If you climbed a mountain carrying a mercury barometer, would the level of the mercury column in the glass tube of the barometer increase or decrease as you climb the mountain? Explain.



Ans. The level of the mercury barometer will decrease as you climb the mountain.

Explanation:

As we rise to mountains, the air pressure decreases. When air pressure decreases, the pressure on the mercury inside barometer also decreases. This decrease in pressure on the mercury

leads to a decrease in the mercury level in column as shown in the figure.

(2) Walnuts can be broken in the hand by squeezing two together but not one. Why?

Ans. It is because the area of contact decreases between two walnuts which lead to a larger pressure. That causes it to break easily than taking one.

Explanation:

When a single walnut is taken then the pressure by your hands act on it from all sides. On the other hand, taking two walnuts decreases the area of contact and thus pressure increases by the relation.

$$P = \frac{F}{A}$$

Thus, decrease in area causes larger pressure on walnut and breaks easily.

(3) Why is the cutting edge of the knife made very thin?

Ans. The cutting edge of the knife is made very thin as to decreases the contact area causing an increase in pressure which cuts easily.

Explanation:

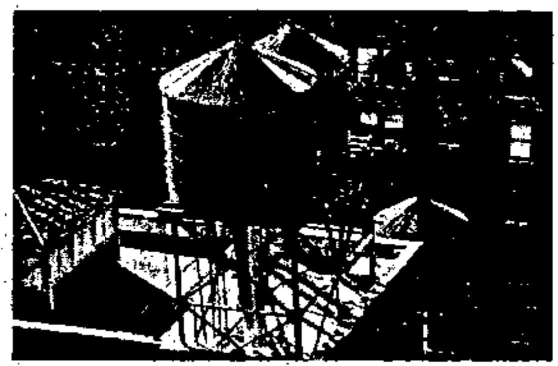
Decreasing the area of the cutting-edge increases pressure by the relation

$$P = \frac{F}{A}$$

For high value of pressure, a little force can produce a larger effect. Sharper the cutting edge of the knife, more easily it can cut the things with a little force.

(4) Why water tanks are constructed at the highest level in our houses?

Ans. The water tanks are constructed/installed at the highest level in our house as to increase the pressure of the water down in the tap/shower.



Explanation:

Greater the height of the fluid, greater the pressure will be

$$P = \rho g h$$

This is why the water tanks are installed at highest level in houses. For public tube wells the height of water tank is kept very large so that the water comes down to houses at higher pressure.

(5) Why a small needle sinks in water and huge ships travel easily in water without sinking?

Ans. A small needle sinks in water and huge ships travel easily in water because of different buoyant forces on both bodies (Archimedes principle).

Explanation:

According to Archimedes principle, if weight of an object is greater than that of displaced fluid the object will sink, otherwise the object will float. Here needle sinks in water because its weight is greater than that of displaced water. In case of huge ships, the weight of displaced water is equal to weight of ship that is why it floats on water surface with partially submerged.

(6) Explain how and why camels have adapted to allow them to walk more easily in desert conditions?

Ans. The structure of the feet of camel is flat and wide. This increases the contact area of it on the ground in desert conditions and thus decreases the exerted pressure given by

$$P = \frac{F}{A}$$

Explanation:

Increasing area causes larger contact between sand and feet. Due to which pressure decreases by the feet on sand. Decrease in pressure keeps the feet to the upper surface and not inserted in sand.

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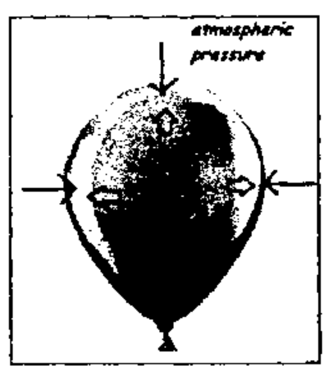
(7) You would have probably experienced your ears 'popping' while driving in the mountains. Why ears 'pop'?

Ans. It is because of the decrease in the atmospheric pressure that you would probably experience your ears popping while driving in the mountains.

Explanation:

The space inside of the eardrum is usually at the same pressure as the outside pressure. But when you go up to mountains, the atmospheric pressure decreases. That causes your ears popping while driving in the mountains.

(8) If you filled an airtight balloon at the top of a mountain, would the balloon expand or contract as you descend the mountain? Explain.



Ans. The balloon will contract when you fill an airtight it at the top of mountains and then bring it down.

Explanation:

When you fill a balloon up at the

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mountains, the external atmospheric pressure and internal pressure on balloon's walls by air balances each other as shown in figure. As you go down the mountains, atmospheric pressure increases but the internal pressure remains the same. This increase in atmospheric pressure causes the contraction of balloon.

(9) A rowboat is floating in a swimming pool. When the anchor is dropped, will the water level in the swimming pool increase, decrease, or remain the same? Explain.

Ans. When you put the anchor into the water, the pool's water level goes down a bit.

Explanation:

When the anchor is in the boat, the mass of the anchor is part of the mass of the boat - which is displacing an equal mass of water in order to float. When the anchor is in the water, the mass of the anchor is no longer part of the mass of the boat and the water line on the boat (and in the pool) actually goes down a bit.

(10) Which material is more elastic, steel or rubber and why?

Ans. Steel is more elastic than rubber because steel comes back to its original shape faster than rubber when the deforming force is removed. Another reason is that for a given stress (stretching force per unit area) strain is much smaller in steel than in rubber which increases the elasticity of the steel as compared to rubber. Mathematically,

$$\text{Elastic modulus} = \frac{Stress}{Strain}$$

Explanation:

When you apply stress on rubber and steel, rubber deforms more easily than steel. When the deforming force is removed, steel attains its original shape more quickly than rubber within elastic limit. This is why we say that steel is more elastic than rubber.

NUMERICAL PROBLEMS

(1) A rectangular glass block of dimensions 30cm by 5cm by 10cm weighs 37.5N. Calculate the least and the greatest pressure it can exert when resting on a horizontal table?

Solution:

Given:

Length L = 30 cm = 0.3 m

Height h = 10 cm = 0.1 m

Width w = 5 cm = 0.05 m

Weight W = 37.5 N

Required: Least pressure P_1 =?

Greatest pressure P_2 =?

Pressure is defined as

$$P = \frac{F}{A}$$

Pressure will be maximum for smaller area and minimum for the larger area. Area is maximum for $A_1 = L \times h = 0.3 \times 0.1 = 0.03 m^2$ and minimum for

$A_2 = w \times h = 0.05 \times 0.1 = 0.005 m^2$

The minimum pressure will be

$$P_1 = \frac{F}{A_1} = \frac{37.5}{0.03} = 1250 Nm^{-2} = \boxed{1250 pa}$$

And the maximum pressure will be

$$P_2 = \frac{F}{A_2} = \frac{37.5}{0.005} = 7500 Nm^{-2} = \boxed{7500 pa}$$

(2) What is the height of a water barometer at atmospheric pressure?

Solution:

Given:

Atmospheric pressure $P = 1 atm = 1.013 \times 10^5$ Pa

Acceleration due to gravity $g = 9.8 ms^{-2}$

Density of water $\rho = 1000 kgm^{-3}$

Required: Height h =?

Pressure is given by the relation

$$P = \rho g h \Rightarrow h = \frac{P}{\rho g}$$

Putting values

$$h = \frac{1.013 \times 10^5}{1000 \times 9.8} = \boxed{10.34 m}$$

(3) The small piston of a hydraulic lift has an area of $0.20 m^2$. A car weighing 1.20×10^4N sits on a

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rack mounted on the large piston. The large piston has an area of $0.90m^2$. How large a force must be applied to the small piston to support the car?

Solution:

Given:

Area of hydraulic lift $A_1 = 0.20\ m^2$

Area of Large piston $A_2 = 0.90\ m^2$

Weight of the car $w = F_2 = 1.20 \times 10^4\ N$

Required: Force on small piston $F_1 = ?$

The ratio of forces is equal to the ratio of the areas upon which it applied.

$$\frac{F_1}{F_2} = \frac{A_1}{A_2}$$

$$\Rightarrow F_1 = \frac{A_1}{A_2} \times F_2$$

Putting values

$$F_1 = \frac{0.20}{0.90} \times 1.20 \times 10^4 = \boxed{2.67 \times 10^3 N}$$

(4) The deepest point in the ocean is 11 km below sea level, deeper than Mt. Everest is tall. What is the pressure in atmospheres at this depth?

Solution:

Given:

Depth of ocean $h = 11\ km = 11 \times 10^3\ m$

Density of sea water $\rho = 1030 kgm^{-3}$

Atmospheric pressure P= 1atm = 1.013×10^5 Pa

Required: Pressure at deep sea P =?

The pressure below water is the sum of atmospheric pressure and the pressure because of water so,

$P = P_{atm} + \rho gh$

Putting values

$P = 1.013\times10^5 + 1030\times9.8\times11\times10^3$

$P = 1.11\times10^8 Pa = \boxed{1.10\times10^3 atm}$

(5) A block is fully immersed in water. Before the immersion the block weighed 30N and while immersed, its apparent weight was found to be 25N. Calculate (a) the up thrust on the block (b) the weight of the water displaced, (c) the volume of water displaces, (d) the volume of the block and (e) the density of the block.

Solution:

Given:

Weight of block in air W_{air} = 30N

Apparent weight in water W_{water} = 25 N

Required: (a) Up thrust U =?

(b) Weight of displaced water $W_{d.w}$ =?

(c) Volume of displaced water $V_{d.w} = ?$

(d) Volume of block $V_B = ?$

(e) Density of the block $\rho = ?$

(a) The up thrust is given by

$$U = W_{air} - W_{water} = 30 - 25 = \boxed{5N}$$

(b) Weight of the water displaced is equal to up thrust so,

Weight of water displaced $W_{d.w} = \boxed{5N}$

(c) Volume is given by

$$V_{d.w} = \frac{m_{d.w}}{\rho} = \frac{w_{d.w}}{\rho g}$$

Putting values

$$V_{d.w} = \frac{5}{1000 \times 9.8} = \boxed{0.00051 m^3}$$

(d) Volume of block will be the same as that of the displaced water according to Archimedes Principle and will be

$$V_B = \boxed{0.00051 m^3}$$

(e) Density of the block will be given by

$$\rho = \frac{m_B}{V_B} = \frac{w_B}{V_b g}$$

Putting values

$$\rho = \frac{30}{0.00051 \times 9.8}$$

$$\boxed{\rho = 6 \times 10^3 kgm^{-3}}$$

(6) When a weight of 30 N is hung from a wire of original length 2.0 m, its new length becomes 2.20 m. Calculate the force constant for the wire, if the elastic limit is not exceeded?

Solution:

Given:

Weight w = F = 30 N

Original length L = 2.0 m

New length L' = 2.20 m

Required: Force constant k =?

From Hooke's law

$$F = -kx$$

$$\Rightarrow k = \frac{F}{x} = \frac{F}{L' - L}$$

Putting values

$$k = \frac{30}{2.20 - 2.0} = \frac{30}{0.20} = \boxed{150 Nm^{-1}}$$

(7) An 80-cm-long, 1.0-mm-diameter steel guitar string must be tightened to a tension of 2000N by turning the tuning screws. By how much is the string stretched?

Solution:

Given:

Length of string L = 80 cm = 0.8 m

Diameter D = 1.0 mm

Radius $r = 0.5\ mm = 5 \times 10^{-4}\ m$

Area $A = \pi r^2 = 3.14\ (5 \times 10^{-4})^2 = 7.75 \times 10^{-7}\ m^2$

Tension in string $T = F = 2000\ N$

Young modulus $Y = 20 \times 10^{10}\ Nm^{-2}$

Required: Change in length $x = ?$

From the definition of young's modulus

$$Y = \frac{Stress}{Strain} = \frac{F \times L}{A \times x}$$

$$\Rightarrow x = \frac{F \times L}{A \times Y}$$

Putting values

$$x = \frac{2000 \times 0.8}{7.75 \times 10^{-7} \times 20 \times 10^{10}} = 1.03 \times 10^{-2} m$$

$$\boxed{x = 1.03 cm}$$

--❀❀❀--

Unit 8

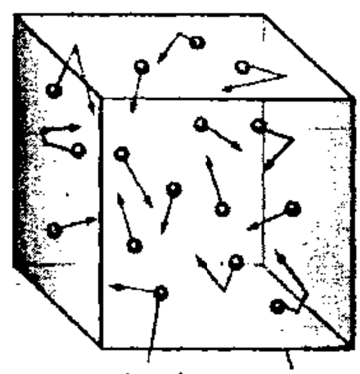
Thermal Properties of Matter

Q.1: Explain the terms internal energy and temperature. Use kinetic theory to distinguish between heat, internal energy and temperature.

Ans. **Internal Energy:**

The sum of all the kinetic and potential energies associated with the motion of the Particles (atoms, ions, molecules etc.) of the substance is called as internal energy of that substance.

Explanation:



Consider a gas (oxygen for example) inside a container as shown in the figure. These molecules can have translational, rotational and vibrational kinetic energies in motion. They also have at the same time some amount of potential energy. The sum of all these energies gives internal energy of the system. It is denoted by u or E_{int}.

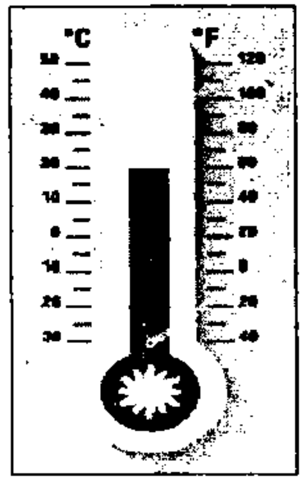
As it is a form of energy so its unit is joule and is a scalar quantity.

Temperature:

The degree of hotness of a body expressed in terms of any of several arbitrary scales is called as temperature.

OR

The average kinetic energy of molecules of a body is called as temperature.



Explanation:

Temperature of a body actually gives the idea of how hot the body is. We know that water at 100C° is very hard to touch as it will burn our skin but water with 20C° can easily be drunk. Which mean that water at 100C⁰ has more internal energy than water at 20C°.

Units and nature:

SI unit of temperature is kelvin (K) but can also be measured in Celsius (C°) and Fahrenheit (F°). It is a scalar quantity.

Heat, internal energy and temperature in Kinetic theory:

Using the kinetic theory, we can make a clear distinction between temperature, heat, and internal energy. Temperature (in kelvins) is a measure of the average kinetic energy of individual molecules. Internal energy refers to the total energy of all the molecules within the object. (Thus, two equal-mass hot ingots of iron may have the same temperature, but two of them have twice as much internal energy as one does). Heat refers to a transfer of energy from one object to another because of a difference in temperature.

Q.2: How do we measure temperature? Explain liquid in glass thermometer.

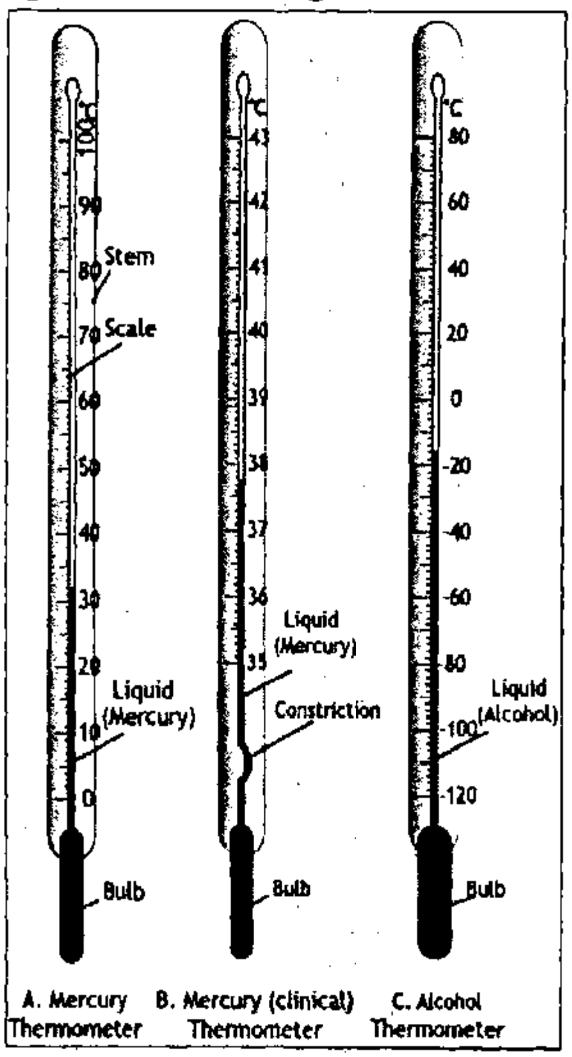
Ans. Temperature could be measured in a simple way by using our hand to sense the hotness or coldness of an object. However, the range of temperatures that

our hand can bear is very small, and our hand is not precise enough to measure temperature correctly.

For scientific work, we need some reliable device or instrument to measure temperature accurately. Such an instrument is called thermometer.

Liquid in glass thermometer:

The Liquid in Glass thermometer utilizes the variation in volume of a liquid in temperature. They use the fact that most fluids expand on heating. The fluid is contained in a sealed glass bulb, and its expansion is measured using a scale etched in the stem of the thermometer.



A. Mercury Thermometer B. Mercury (clinical) Thermometer C. Alcohol Thermometer

If we consider that the thermometer does not expand then as a physical property it utilizes the variation of length of liquid with temperature. In this type the liquid in a glass bulb expands up a capillary tube when the bulb is heated. The liquid must easily be seen and must expand (or contract) rapidly and by a large amount over a wide range of temperature. It must not stick to the

inside of the tube or the reading will be too high when the temperature is falling. Liquids commonly used include Mercury and Alcohol.

Q.3: What are various temperature scales? Derive mathematical expressions to convert between various scales of temperature.

Ans. *The scale which is made for the measurement of temperature is called temperature scale or thermometric scale. The scale comprises of two reference points, called fixed points.* These points are given arbitrarily assigned numerical values.

There are following three scales used for the measurement of temperatures.

(1) <u>The kelvin scale (K):</u>

This scale was devised by William Thomson, (Lord Kelvin). He named this scale as absolute scale. In this scale of temperature, the ice point is marked as 273K and the boiling point of water marked as 373K. Thus, the interval between them is divided into 100 equal parts. Each part on the scale is called one Kelvin and denoted by K. It is the SI unit of temperature measurement.

(2) <u>The Celsius Scale (°C):</u>

This scale was introduced by a Swedish astronomer Anders Celsius. In this scale of temperature, the ice point is marked as 0°C and the steam fixed point is marked as 100°C at standard pressure. The interval between these two fixed points is divided into 100 equal parts (divisions). Each division on the scale is called one degree centigrade or Celsius and denoted by °C. It is the most commonly used unit of temperature for the weather and

climate. For example, we say that today's temperature is 25°C.

(3) The Fahrenheit Scale (°F):

This scale was introduced by German physicist Daniel Gabriel Fahrenheit. In this scale of temperature, the ice point is marked as 32°F and the steam point is marked as 212°F. The interval between these points is divided into 180 equal parts. Each part on the scale is called on degree Fahrenheit and is denoted by °F. It is mostly used for body's temperature. For example, we say that this patient's temperature is 101°F.

Note:

There is a temperature value for which both the Celsius and Fahrenheit are equal to each other and its value is –40.

Absolute zero/Kelvin zero:

The temperature at which all motions of particles inside matter stops/ceases. Its value is 0K or –273.15°C or –459.67°F. Practically this temperature is impossible to achieve.

Conversion of different scales:

A temperature measured on one scale, sometimes, needs conversion to another scale. Let °C, °F and K, are measured on three scales. A general relation for the conversion of temperature from one scale to the other is as follows:

$$\frac{\textit{Temperature on one scale-Ice point}}{\textit{number of divisions between fixed points}} = \frac{\textit{Temperature on other scale-Ice point}}{\textit{number of divisions between fixed points}}$$

$$\frac{T_{scale1}-T_{ice}}{N}=\frac{T_{scale2}-T_{ice}}{N}$$

For the given three scales we will use the following general formula.

$$\frac{T_{^oC}-0^oC}{100}=\frac{T_K-273}{100}=\frac{T_{^oF}-32}{180}$$

Taking any two from above, put value of one scale you will get the equivalent for another scale. A more specific relation between any of the three scales is given by

$$T_K=T_{^oC}+273\rightarrow\boxed{1}$$

$$T_{^oC}=\frac{T_{^oF}-32}{1.8}\rightarrow\boxed{2}$$

$$T_{^oF}=1.8T_{^oC}+32\rightarrow\boxed{3}$$

Q.4: What is meant by linear thermal expansion and volume thermal expansion of solids?

Ans. (1) <u>Linear thermal expansion:</u>

The increase in length of a substance due to rise in temperature is called linear thermal expansion.

<u>Explanation:</u>

Thermal expansion means increase in size of a substance on heating. When this increase is in length then it is called as linear thermal expansion. Consider a metal rod having an original length 'L_o', at temperature 'T_o'. After heating metal rod (an increase in temperature by ΔT) to temperature '$T=T_o+\Delta T$', the rod expands (by an amount ΔL) to its new length '$L_T=L_o+\Delta L$' as shown in the figure.

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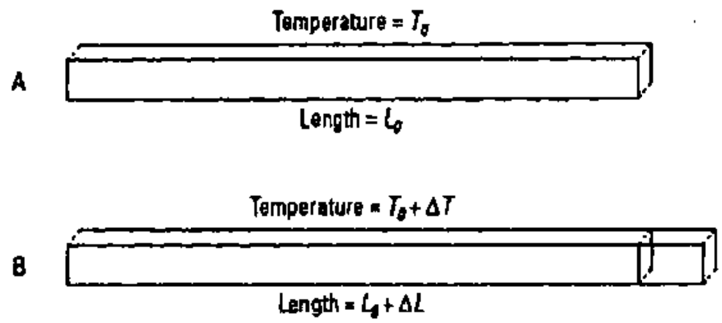


Experiments indicate that the change in length ΔL of almost all solids is, to a good approximation, directly proportional to the change in temperature ΔT as long as it is not too large.

Mathematically,

$\Delta L \propto \Delta T$

Change in length due to linear thermal expansion is also directly proportional to the initial length (L_o) given by

$\Delta L \propto L_o$

Combining these two proportionalities gives $\Delta L \propto L_o \Delta T$. Putting equality sign in place of proportionality we will get

$\Delta L = \alpha L_o \Delta T$

Whereas α is proportionality constant and is called "the coefficient of linear thermal expansion" for the particular material and has units of $°C^{-1}$ and K^{-1}.

Putting $\Delta L = L_T - L_o$ in above equation we will get

$L_T - L_o = \alpha L_o \Delta T$

$\Rightarrow L_T = L_o(1 + \alpha \Delta T)$

Coefficient of linear expansion can be defined as the change in length per unit original length per degree rise in temperature. Mathematically

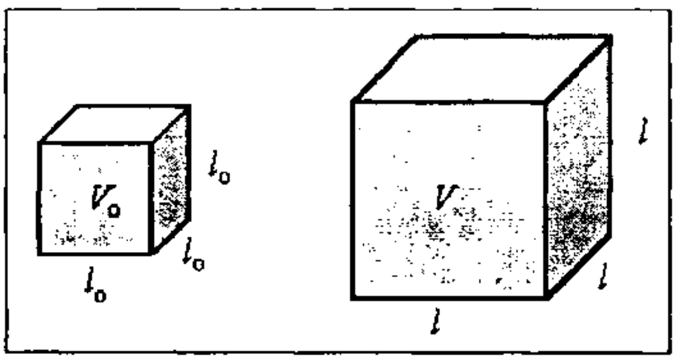
$$\alpha = \frac{\Delta L}{L_o \Delta T}$$

(2) <u>Volume thermal expansion:</u>

The increase in volume of a substance due to rise in temperature is called volume thermal expansion.

<u>Explanation:</u>

Thermal expansion means increase in size of a substance on heating. When this increase is in volume it is called as volume thermal expansion. Consider a metal block having an original volume 'V_o', at temperature 'T_o'. After heating metal block to temperature 'T', the block expands to its new volume 'V' as shown in the figure.



This means that for a change in temperature ΔT (where $\Delta T = T - T_o$) there is corresponding change in volume ΔV (where $\Delta V = V - V_o$). The increase in volume of a metal block, on heating, is directly proportional to original volume of the metal block and the rise in temperature.

Mathematically,

$$\Delta V \propto \Delta T$$

$$\Delta V \propto V_o$$

Combining these two and replacing proportionality with a constant γ called as coefficient of volume thermal expansion.

Mathematically,

$$\Delta V \propto V_o \Delta T$$

$$\Delta V = \gamma V_o \Delta T$$

$$V - V_o = \gamma V_o \Delta T$$

$$V = V_o(1 + \gamma \Delta T)$$

From above equation we can easily find the new volume after expansion.

Coefficient of volume thermal expansion is defined as the change in volume per unit original volume per degree rise in temperature.

Mathematically,

$$\gamma = \frac{\Delta V}{V_o \Delta T}$$

Q.5: Find the relation between α and γ.

Ans. The coefficient of linear thermal expansion and the coefficient of volume thermal expansion are related as

$$\gamma = 3\alpha$$

Proof:

To see how this relationship comes about, suppose that the solid has the shape of a cube of side L. The increment in the length of each side is L, and treating this as a small (infinitesimal) quantity, the increment in the volume L^3 is

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$$\Delta V = \Delta(L)^3 = 3L^2\Delta L = 3L^2 \times \alpha L\Delta T$$

$$\Delta V = 3\alpha L^3\Delta T = 3\alpha V\Delta T$$

From volume thermal expansion

$$\Delta V = \gamma V\Delta T$$

Comparing these two we get

$$\gamma = 3\alpha$$

Material	Coefficient of Linear Expansion, α $(C°)^{-1}$	Coefficient of Volume Expansion, β $(C°)^{-1}$
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	56×10^{-6}
Copper	17×10^{-6}	50×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	35×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Glass (Pyrex®)	3×10^{-6}	9×10^{-6}
Glass (ordinary)	9×10^{-6}	27×10^{-6}
Quartz	0.4×10^{-6}	1×10^{-6}
Concrete and brick	$\approx 12 \times 10^{-6}$	$\approx 36 \times 10^{-6}$
Marble	$1.4–3.5 \times 10^{-6}$	$4–10 \times 10^{-6}$
Liquids		
Gasoline		950×10^{-6}
Mercury		180×10^{-6}
Ethyl alcohol		1100×10^{-6}
Glycerin		500×10^{-6}
Water		210×10^{-6}
Gases		
Air (and most other gases at atmospheric pressure)		3400×10^{-6}

Coefficient of expansion near 20 degree celsius

Q.6: What is thermal expansion of liquids? Why we have real and apparent thermal expansion in liquids. Illustrate with the help of an experiment.

Ans. *The increase in the volume of a liquid due to the thermal effect is called thermal expansion of liquids.*

Explanation:

Like solids, liquids also expand on heating and contract on cooling. A liquid has no definite length and surface area; therefore, we cannot consider the linear expansion or superficial expansion of a liquid. But liquids always take the shape of the containing vessel. Therefore, in case of liquids we are concerned only with volume changes when they are heated.

Since heat affects both the liquid and the container, the real expansion of a liquid cannot be detected directly. In case of liquids, we have two kinds of thermal expansion: the apparent expansion and the real expansion.

A. Real expansion of liquid:

A real increase in the volume of a liquid, that takes place due to increase of temperature is called real expansion V_R of liquid. This expansion is independent of the expansion of the container.

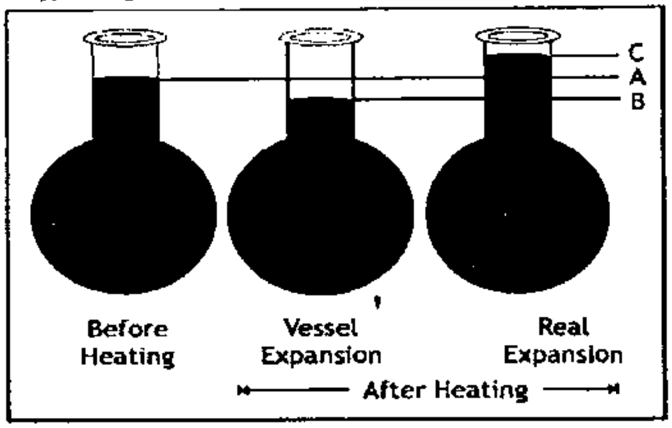
B. Apparent expansion of liquid:

An apparent increase in the volume of a liquid, that takes place due to increase of temperature is called apparent expansion V_A of liquid.

When a liquid is taken in a container and heated, both the liquid and the container expand at the same time. The difference of these expansions is called apparent expansion.

If V_R is the expansion in the volume of the liquid (called real expansion) and V_C is the expansion in the volume of the container on heating then the apparent expansion V_A is given by as;

$V_A = V_R - V_C$



Experiment:

Let a vessel has water up to level A. If heat is applied, the vessel will first expand which will produce an illusion that the water has fallen. This is due to the expansion of the vessel and is given by the measurement of the difference of the two levels i.e. AB. If heating is further done, heat energy will start reaching the liquid. The liquid will then start expanding rapidly, according to its nature, exceeding its previous level, to reach up to level C. So, the measurement of BC gives the true (real) expansion of the liquid only. An observer who was present at the start and at the end will see the whole episode as just the expansion of the liquid from A to C. So, AC measures the apparent expansion of the body.

Mathematically,

BC = AC + AB

Or, Real Expansion of liquid =

Apparent Expansion of liquid + Vessel Expansion

Coefficient of real expansion (γ_R):

It is defined as the real increase in volume of liquid per unit original volume per degree rise in temperature. It is defined as:

$$\gamma_R = \frac{Real\ increase\ in\ volume}{original\ volune \times change\ in\ temperature}$$

Its unit is per degree rise in temperature i.e. $^{o}C^{-1}$ or K^{-1}.

Coefficient of Apparent expansion (γ_A):

It is defined as the apparent increase in volume of liquid per unit original volume per degree rise in temperature. It is defined as:

$$\gamma_A = \frac{Apparent\ increase\ in\ volume}{original\ volune \times change\ in\ temperature}$$

Its unit is per degree rise in temperature i.e. $^{o}C^{-1}$ or K^{-1}.

Q.7: Define heat capacity and specific heat capacity of a substance. Explain the importance of high specific heat capacity of water.

Ans. Heat capacity (c_m):

The quantity of heat required raise the temperature of a substance of mass (m) by 1°C or 1 K is called the heat capacity (c) of that substance.

Explanation:

If ΔQ is the change in heat and ΔT is the change in temperature, then

$$c_m = \frac{\Delta Q}{\Delta T}$$

The value of 'c_m' depends upon

- The nature of the material of the substance.
- The mass of the material of the substance.

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- The rise in temperature.

In the Standard International System, the unit of heat capacity is joule per Kelvin which is expressed as J K^{-1}.

Specific heat capacity:

The quantity of heat required raise the temperature of unit mass (1.0 kg) of the substance by 1°C or 1K is called specific heat capacity of that substance.

Substance	c J kg^{-1} K^{-1}	Substance	c J kg^{-1} K^{-1}
Aluminium	900	Ice	2100
Iron/steel	450	Wood	1700
Copper	390	Nylon	1700
Brass	380	Rubber	1700
Zinc	380	Marble	880
Silver	230	Concrete	850
Mercury	140	Granite	840
Tungsten	135	Sand	800
Platinum	130	Glass	670
Lead	130	Carbon	500
Hydrogen	14000	Ethanol	2400
Air	718	Paraffin	2100
Nitrogen	1040	Water	4186
Steam	2000	Sea water	3900

Explanation:

If ΔQ is the change in heat, m is mass of substance and ΔT is the change in temperature then

$$c = \frac{c_m}{m}$$

$$\text{Or } c = \frac{\Delta Q}{m\Delta T}$$

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The S.I. unit of specific heat capacity or specific heat is joule per kilogram per Kelvin which is expressed as J kg^{-1} K^{-1}.

Different substances have different specific heat. The quantity of heat needed also depends on the nature of the material; raising the temperature of 1 kilogram of water by 1K (1°C) requires 4186J of heat, but only 900J is needed to raise the temperature of 1 kilogram of aluminium by 1K (1°C). The specific heat of water at 20°C is 4186J $kg^{-1}K^{-1}$. No other substance has a high specific heat capacity and it has natural benefits in sustaining life on the planet earth.

Importance of high specific heat capacity of water:

Following are the important implications of high specific heat capacity of water.

(a) Moderate climate of sea shore:

The specific heat of sand is about 800J kg^{-1} K^{-1}. A certain mass of water needs five times more heat than the same mass of soil for its temperature to raise by 1°C or 1 K. Hence, the land gets heated much more easily than water. Also, it cools down much easily. Hence, a large difference in temperature is formed that gives rise to land breeze and sea breeze. It keeps the climate of the coastal areas moderate. Monsoon in Pakistan is also due to the difference in temperature between the land and the surrounding sea.

(b) As a coolant:

Water is used as an effective coolant. By allowing water to flow in radiator pipes of the vehicles, heat energy form such parts is removed. Thus, water extracts much heat without much rise in temperature.

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Q.8: What is meant by the latent heat of fusion and latent heat of vaporization of a substance?

Ans. Latent heat of fusion:

The amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state (melt) without any rise in temperature is called its latent heat of fusion.

Liquids release the same amount of heat when they solidify (freeze).

Specific latent heat of fusion of solids:

The amount of heat energy required to convert unit mass (one kilogram) of the solid at its melting point to liquid, (or liquid into solid) without any change in temperature is called its specific latent heat of fusion of the solid.

Explanation:

If 'ΔQ' is the amount of heat energy needed to melt mass 'm' of a solid to liquid (or freeze liquid to solid), then mathematically,

$$\Delta Q = mL_f$$

Whereas L_f is called as specific latent heat of fusion of solids. Its unit is joule per kilogram and is given by

$$L_f = \frac{\Delta Q}{m}$$

Its value depends upon the nature of substance as shown in the given table.

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Helium	- 269.65	5.23×10^3	- 269	2.09×10^4
Oxygen	- 218.79	$1.38 \times \times 10^4$	-183	2.13×10^5
Water	0	$3.33 \times \times 10^5$	100	2.26×10^6
Mercury	-39	$1.13 \times \times 10^4$	357	2.93×10^5
Sulphur	119	$3.81 \times \times 10^4$	445	3.26×10^5
Lead	327	$2.45 \times \times 10^4$	1750	8.70×10^5
Aluminum	660	$3.97 \times \times 10^5$	2450	1.14×10^7
Copper	1083	1.34×10^5	1187	5.06×10^6
Silver	961	8.82×10^4	2193	2.33×10^6
Gold	1063	6.44×10^4	2660	1.58×10^6

Latent heat of vaporization:

The amount of heat energy required to convert a given mass of a substance from liquid state to gaseous state (boil) without any rise in temperature is called its latent heat of vaporization.

Gases release the same amount of heat when they Liquify (condense).

Specific Latent heat of vaporization:

The amount of heat energy required to convert unit mass (one kilogram) of the liquid at its melting point to gas, (or gas into liquid) without any change in temperature is called its specific latent heat of vaporization of the solid.

Explanation:

If 'ΔQ' is the amount of heat energy needed to vaporize mass 'm' of a liquid to gas (or condense gas to liquid), then mathematically

$$\Delta Q = mL_v$$

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Whereas, L_v is called as specific latent heat of vaporisation of liquids. Its unit is joule per kilogram and is given by

$$L_v = \frac{\Delta Q}{m}$$

Its value depends upon the nature of substance as shown in the table.

Q.9: What is meant by evaporation? On what factors the evaporation of a liquid depends. Explain how cooling is produced by evaporation. Differentiate between boiling and evaporation.

Ans. Evaporation:

The process by which a liquid slowly changes into its vapours at any temperature (below its boiling point) without the aid of any external source of heat is called evaporation of liquids.

Explanation:

We know that the molecules of a liquid move with wide of range of instantaneous velocities and they have different kinetic energies ranging from minimum to a very high value. Some of the molecules, having sufficient kinetic energy, overcome the forces of attraction, leave the surface of the liquid and escape out in the form of vapours. We call this escaping of the high energy molecules as evaporation.

Factors upon which evaporation of a liquid depends:

Evaporation of liquids depends on the following factors.

(1) Nature of liquid:

Liquid with low boiling points evaporates more rapidly than those with higher boiling points. For example, the rate of evaporation of alcohol is higher than that of water.

(2) Temperature of liquid:

Due to higher temperature, molecules of liquid at the surface will have more kinetic energy and chances of escaping will increase and evaporation will be fast. This can be seen while ironing clothes. Under a hot iron wet clothes dry out quickly as the water evaporates quickly.

(3) Temperature of surrounding:

The higher the temperature of the surrounding the higher is the rate of evaporation. It is for this reason that wet clothes dry rapidly in summer than in winter.

(4) Presence of water vapour in Air:

The more the amount of water vapour present in air, the less is the rate of evaporation. It is for this reason, that wet clothes dry slowly in rainy season as a lot of water vapour are present in the air.

(5) Area of the exposed surface of the liquid:

Increased surface area gives the molecules a greater chance of escaping. Wet roads dry out quickly because the rain water is spread over a large area.

(6) Movement of Air:

The more rapid the flow of air, the higher is the rate of evaporation. It is for this reason that wet clothes dry more rapid on a windy day compared on a calm day.

(7) Dryness of Air:

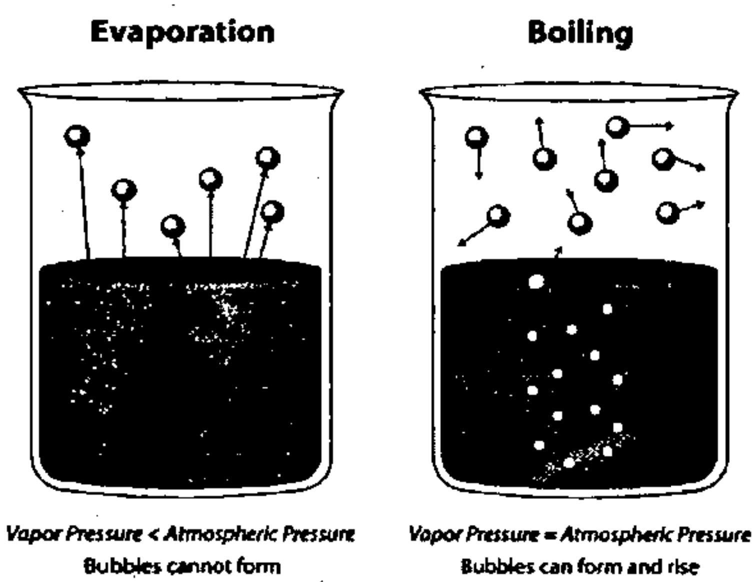
Drier the air, the more rapid is the evaporation. Presence of water vapour reduces the rate of evaporation. Desert room coolers are more effective in cooling by evaporation in the dry month of June than it is in the humid month of August.

(8) Air pressure on the surface of the liquid:

The lower the pressure on the surface of the liquid, higher is the rate of evaporation.

Cooling by evaporation:

When a liquid evaporates, its molecules convert from the liquid phase to the vapor phase and escape from the surface. The process that drives it is latent heat. In order for the molecule to leave the liquid surface and escape as a vapor, it must take heat energy with it. Since the molecule is taking heat with it as it's leaving, this has a cooling effect on the surface left behind.



For example, spirit spilled on your palm quickly evaporates. As a result, your palm feels cold. Water evaporates much slower than ether and spirit.

Evaporation of water also produces cooling. You can feel the chilling effect of the evaporation of water if you sit under a fan and wearing wet clothes. Perspiration in a human body helps to cool the body and to maintain a stable body temperature.

Comparison of boiling and evaporation:

Boiling	Evaporation
A process in which a substance changes its state from the liquid state to the gaseous state	Evaporation is a process whereby the water changes into vapour without boiling
Quick	Slow
Bubbles are formed	No bubbles formed
Occurs throughout the liquid	Takes place only from the exposed surface of the liquid
Occurs at a definite temperate-- boiling point	Occurs at all temperature
Source of energy needed	Energy supplied by surroundings

Examples and Assignments:

EXAMPLE # 8.1:

HUMAN BODY TEMPERATURE

The temperature of a normal human body is 37°C. Find this temperature on the Fahrenheit and Kelvin Scale.

Solution:

Given:

Temperature in Celsius $T_{^\circ C} = 37^\circ C$

Required: Temperature in Kelvin $T_K = ?$

Temperature in Fahrenheit $T_{^\circ F} = ?$

The relation between kelvin and Celsius scale is given by

$T_K = T_{°C} + 273$

Putting value of $T_{°C}$ in above equation

$T_K = 37 + 273 = \boxed{310K}$

The relation between Fahrenheit and Celsius scale is given by

$T_{°F} = 1.8T_{°C} + 32$

Putting value of $T_{°F}$ in above equation

$T_{°F} = 1.8 \times 37 + 32 = \boxed{98.6°F}$

ASSIGNMENT 8.1:

KELVIN SCALE

Temperature of an object is 250 K. Find its temperature in centigrade.

Solution:

Given:

Temperature in kelvin $T_K = 250K$

Required: Temperature in Celsius $T_{°C} = ?$

The relation between kelvin and Celsius scale is given by

$T_K = T_{°C} + 273 \Rightarrow T_{°C} = T_K - 273$

Putting value of T_K in above equation

$T_{°C} = 250 - 273 = \boxed{-23°C}$

EXAMPLE 8.2:

BRIDGE ENGINEERING

The steel ($\alpha = 12 \times 10^{-6}\ K^{-1}$) bed of a suspension bridge is 200m long at 20°C. If the extremes of temperature to which it might be exposed are –5°C to 50°C how much will it contract and expand?

Solution:

Given:

Original length $L_o = 200m$

Reference temperature $T_o = 20°C$

Required: (a) Change in length $\Delta L_1 = ?$

(b) Change in length $\Delta L_2 = ?$

Coefficient of linear thermal expansion

$\alpha = 12 \times 10^{-6} k^{-1}$

Temperature $T_1 = -5°C$

Temperature $T_2 = 50°C$

(a) When temperature decreases to –5°C the change in temperature will be given by

$$\Delta T_1 = T_1 - T_o = -5 - 20 = -25°C = -25K$$

The linear thermal expansion is given by

$$\Delta L_1 = \alpha L_o \Delta T_1$$

$$\Delta L_1 = 12 \times 10^{-6} \times 200 \times (-25)$$

$$\Delta L_1 = -6 \times 10^{-2} m = \boxed{-6cm}$$

The negative sign shown decrease in length i.e. it will contract.

(b) When temperature increases to 50°C the change in temperature will be given by

$$\Delta T_2 = T_2 - T_o = 50 - 20 = 30°C = 30K$$

The linear thermal expansion is given by

$$\Delta L_2 = \alpha L_o \Delta T_2$$

$$\Delta L_2 = 12 \times 10^{-6} \times 200 \times (30)$$

$$\Delta L_2 = 7.2 \times 10^{-2} m = \boxed{7.2cm}$$

Here change in length is positive which means that there will be increase in length.

The total range of expansion joints must accommodate is 7.2 cm + 6 cm = $\boxed{13.2cm}$.

ASSIGNMENT 8.2:

COEFFICIENT OF LINEAR THERMAL EXPANSION

The length of a bar of certain metal is 60cm. When the bar is heated from 8°C to 100°C, its length becomes 60.127cm. Calculate the coefficient of linear thermal expansion of the metal.

Solution:

Given:

Original length L_1 = 60cm = 0.6m

New Length L_2 = 60.127cm = 0.60127m

Temperature T_1 = 8°C = 281K

Temperature T_2 = 100°C = 373K

Required: Coefficient of linear thermal expansion α=?

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The coefficient of linear thermal expansion is given by

$$\alpha = \frac{\Delta L}{L_1 \Delta T} = \frac{L_2 - L_1}{L_1(T_2 - T_1)}$$

Putting values

$$\alpha = \frac{0.60127 - 0.60}{0.60(373 - 281)}$$

$$\alpha = \frac{0.00127}{55.2} = \boxed{2.3\times10^{-5} K^{-1}}$$

EXAMPLE 8.3:

GLASS LASER EXPANSION

The active element of a certain laser is made of a glass rod 30.0cm long and having volume $5.30\times10^{-5} m^3$. Assume the average coefficient of linear expansion of the glass is equal to 9.00×10^{-6} K^{-1}. If the temperature of the rod increases by 65.0°C, what is the increase in (a) its length and (b) its volume?

Solution:

Given:

Original length L_o = 30cm = 0.3m

Original volume $V_o = 5.30\times10^{-5} m^3$

Required: (a) Change in length ΔL = ?

(b) Change in volume ΔV = ?

Coefficient of linear thermal expansion $\alpha = 9\times10^{-6} K^{-1}$

Change in temperature $\Delta T = 65°C = 65K$

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(a) The linear thermal expansion is given by

$$\Delta L = \alpha L_o \Delta T$$

$$\Delta L = 9\times10^{-6}\times0.3\times65$$

$$\Delta L = 1.76\times10^{-4}\,m = \boxed{0.176mm}$$

(b) The volume thermal expansion is given by

$$\Delta V = \gamma V_o \Delta T = 3\alpha V_o \Delta T$$

$$\Delta V = 3\times9\times10^{-6}\times5.30\times10^{-5}\times65$$

$$\boxed{\Delta V = 93.0\times10^{-9}\,m^3}$$

ASSIGNMENT 8.3:

<u>CHANGE IN VOLUME OF LEAD</u>

A $200cm^3$ piece of lead ($\gamma = 87 \times 10^{-6}K^{-1}$) is at 10°C. If it is heated to a temperature of 40°C, find the change in volume of the lead.

<u>Solution:</u>

Given:

Original volume of lead piece $V_o = 200cm^3$

Reference temperature $T_o = 10°C$

New temperature T= –40°C

Temperature difference $\Delta T = T - T_0$

$$= 40 - 10 = 30°C = 30K$$

Coefficient of volume thermal expansion
$\gamma = 87\times10^{-6}K^{-1}$

Required: Change in volume ΔV = ?

The volume thermal expansion is given by

$$\Delta V = \gamma V_o \Delta T$$

Putting values

$$\Delta V = 87 \times 10^{-6} \times 200 \times (30)$$

$$\boxed{\Delta V = 0.522 cm^3}$$

EXAMPLE 8.4:

<u>LOST DIESEL</u>

An oil trucker loaded 37,000 L of diesel fuel with $\gamma = 9.5\times10^{-4}K^{-1}$ at Jackobabad, where on hot day the temperature is 50°C. This oil is transported to Kalam where on cold day the temperature is 0°C. What is the change in volume of diesel? How many litres did the tanker deliver?

<u>Solution:</u>

Given:

Original volume of lead piece V_o = 37,000L

Coefficient of volume thermal expansion

$\gamma = 9.5 \times 10^{-4} K^{-1}$

Temperature difference $\Delta T = T - T_0 = 0 - 50$

$$= -50°C = -50K$$

Required: (a) Change in volume ΔV = ?

(b) Volume delivered V_D = ?

(a) The volume thermal expansion is given by

$$\Delta V = \gamma V_o \Delta T$$

Putting values

$$\Delta V = 9.5 \times 10^{-4} \times 37,000 \times (-50) = -1757.5 = \boxed{-1758L}$$

Negative sign shows decrease in volume of oil.

(b) A decrease of 1758L is observed. So, the delivered amount will be given by

$$\Delta V = V_D - V_o \Rightarrow V_D = V_o + \Delta V$$

$$V_D = 37,000 - 1758 = \boxed{35242L}$$

ASSIGNMENT 8.4:

CHANGE IN VOLUME OF PATROL

If patrol at 0°C occupies 250 litters. What is its volume at 50°C? For patrol $\gamma = 9.6 \times 10^{-4}\ K^{-1}$.

Solution:

Given:

Volume at 0°C, V_o = 250L

Coefficient of volume thermal expansion
$\gamma = 9.6 \times 10^{-4}\ K^{-1}$

Temperature difference $\Delta T = T_{50} - T_o = 50 - 0$

$$= 50\,°C = 50K$$

Required: Volume at 50°C, V_T = ?

The thermal volume expansion is given by

$$\Delta V = \gamma V_o \Delta T$$

$$V_T - V_o = \gamma V_o \Delta T$$

$$V_T = V_o(1 + \gamma \Delta T)$$

Putting values

$$V_T = 250(1 + 9.6 \times 10^{-4} \times 50) = 250(1.048)$$

$$\boxed{V_T = 262L}$$

EXAMPLE 8.5:

AMOUNT OF HEAT TO RAISE THE TEMPERATURE OF WATER

How much heat is required to increase the temperature of 0.5 kg of water (with specific heat capacity of 4190 J kg^{-1} K^{-1}) from 10°C to 65°C?

Solution:

Given:

Mass of water m = 0.5 kg

Initial temperature T_o = 10 °C

Final temperature T = 65 °C

Change in temperature $\Delta T = T - T_o = 65 - 10$

$$= 55°C = 55K$$

Specific heat capacity of water $c = 4190 Jkg^{-1}K^{-1}$

Required: Heat required ΔQ = ?

The specific heat capacity is given by the relation

$$c = \frac{\Delta Q}{m\Delta T} \Rightarrow \Delta Q = cm\Delta T$$

Putting values

$$\Delta Q = 4190 \times 0.5 \times 55 = \boxed{104,750J}$$

ASSIGNMENT 8.5:

SPECIFIC HEAT OF SILVER

If 117.60J of heat is require to raise the temperature of 10g of silver through 50°C. Calculate the specific heat of silver.

Solution:

Given:

Mass of water m = 10g = 0.01 kg

Heat required ΔQ = 117.60J

Temperature difference ΔT = 50°C = 50K

Required: Specific heat of silver C =?

The specific heat capacity is given by the relation

$$c = \frac{\Delta Q}{m\Delta T}$$

$$c = \frac{117.60}{0.01 \times 50} = \boxed{235.2 Jkg^{-1}K^{-1}}$$

EXAMPLE 8.6:

MELTING ICE

Find the amount of heat for melting the ice having mass 1.3 kg at –10°C? (Latent heat of fusion for ice L_f =3.3×10^5 J/kg and specific heat for ice c = 2.2×10^3 J/kg K)

Solution:

Given:

Mass of ice m = 1.3 kg

Initial temperature $T_o = -10\ ^\circ C$

Final temperature $T = 0\ ^\circ C$

Change in temperature $\Delta T = T - T_o = 0-(-10)$

$$= 10^\circ C = 10K$$

Specific heat of ice $c = 2.2 \times 10^3$ J/kg K

Latent heat of fusion $L_f = 3.3 \times 10^5$ J/kg

Required: Heat required $\Delta Q = ?$

First, we will provide heat to increase the temperature of the ice from $-10^\circ C$ to $0^\circ C$ (melting point)

$$c = \frac{\Delta Q_1}{m\Delta T} \Rightarrow \Delta Q_1 = cm\Delta T$$

$$\Delta Q_1 = 2200 \times 1.3 \times 10 = 2.86 \times 10^4 J$$

Now we will find heat required for melting ice at $0^\circ C$, such that

$$\Delta Q_2 = mL_f$$

Putting values

$$\Delta Q_2 = 1.3 \times 3.3 \times 10^5 = 42.9 \times 10^4 J$$

Total heat required will be

$$\Delta Q = \Delta Q_1 + \Delta Q_2$$

$$\Delta Q = 2.86 \times 10^4 + 42.9 \times 10^4 = 45.8 \times 10^4 J$$

$$\boxed{\Delta Q = 4.58 \times 10^5 J}$$

ASSIGNMENT 8.6:

EVAPORATING WATER

Find the amount of heat for evaporating 2.8kg of water at 45°C? (Latent heat of vaporization for water L_v =2.3×10^{6}J/kg and specific heat of water c = 4190J/kg K)

Solution:

Given:

Mass of water m = 2.8 kg

Initial temperature T_o = 45°C

Final temperature T = 100°C

Change in temperature $\Delta T = T - T_o = 100 - 45$

$$= 55°C = 55K$$

Specific heat of water c = 4190 J/kg K

Required: Heat required $\Delta Q = ?$

Latent heat of vaporisation for water

$L_v = 2.3 \times 10^6$ J/kg

First, we will provide heat to increase the temperature of the water from 45°C to 100°C (boiling point)

$$c = \frac{\Delta Q_1}{m\Delta T} \Rightarrow \Delta Q_1 = cm\Delta T$$

$$\Delta Q_1 = 4190 \times 2.8 \times 55 = 6.45 \times 10^5 J$$

Now we will find heat required for boiling water at 100 °C, such that

$$\Delta Q_2 = mL_v$$

Putting values

$$\Delta Q_2 = 2.8\times 2.3\times 10^6 = 64.4\times 10^5 J$$

Total heat required will be

$$\Delta Q = \Delta Q_1 + \Delta Q_2$$

$$\Delta Q = 6.45\times 10^5 + 64.4\times 10^5 = 70.85\times 10^5 J = \boxed{7.1\times 10^6 J}$$

EXERCISE

Multiple Choice Questions:

(1) The S.I. unit of heat is

A. J   B. Kg

C. K^{-1} D. K

(2) The S.I. unit of temperature is

A. °C   B. °F

C. J   D. K

(3) The Fahrenheit and Celsius scale reading of temperature coincide at

A. °0   B. – °460

C. –°273   D. – °40

(4) 310 K in centigrade scale is

A. 37°C   B. 310°C

C. 63°C   D. 273°C

(5) When water at 0^0C is heated, it contracts till temperature reaches

A. 1°C   B. 4°C

C. 100°C   D. 100 K

(6) The S.I. unit of specific heat is

A. JK^{-1} B. $JK^{-1}\ kg^{-1}$

C. $J\ kg^{-1}$ D. JK kg

(7) The relation between coefficient of linear and volume expansion is;

A. $\alpha = 3\gamma$ B. $\gamma = 3\alpha$

C. $\gamma = \alpha/2$ D. $\gamma = 6\alpha$

(8) The S.I. unit of specific Latent heat is

A. JK^{-1} B. $J\ kg^{-1}$

C. $JK\ kg^{-1}$ D. JK kg

(9) How much heat is required to melt of 1kg of Zink at its boiling temperature 240°C with latent heat of $113\times10^3\ J\ kg^{-1}$?

A. 113×10^3 J B. 1.13×10^3 J

C. 2.4×10^5 J D. 2.71×10^7 J

(10) The amount of heat required to raise the temperature of 1 kg of water by 1 K is

A. 1 J B. 400 J

C. 310 J D. 4190 J

ANSWERS:

1.A	2.D	3.D	4.A	5.B	6.B	7.B	8.B	9.A	10.D

CONCEPTUAL QUESTIONS

(1) Ordinary electric fan increases the kinetic energy of the air molecules caused by the fan blades pushing those means the air temperature increases slightly rather than cool the air? Why we use it?

Ans. The reason for using the fan is that it keeps air moving. The human body warms the air immediately around it, assuming the air is initially cooler than the body. If that warmed air stays in contact with the body, then the body will lose little further heat after the air is warmed. The fan, by circulating the air, removes the heated air from close to the body and replaces it with cooler air.

Likewise, the body is also cooled by evaporation of water from the skin. As the relative humidity of the air close to the body increases, less water can be evaporated, and cooling by evaporation is decreased. The fan, by circulating the air, removes the hot, humid air from close to the body and replaces it with cooler, less humid air, so that evaporation can continue.

(2) Why are small gaps left behind the girders mounted in walls?

Ans. Small gaps are left behind the girders mounted in walls to give room for expansion. Usually one end of the iron structure is fixed and the other end is allowed to expand in summer into the left-out gap. Because when summer comes, it comes to its own place therefore small gapes are left behind the girders.

(3) Why you should not put a closed glass jar into a campfire. What could happen if you tossed an empty glass jar, with the lid on tight, into a fire?

Ans. The inside of the jar is not empty. It is filled with air. As the fire heats the air inside, its temperature rises. The volume of the glass jar changes only slightly due to the heating. According to Gay-Lussac's law the pressure *P* of the air inside the jar can increase enough to cause the jar to explode, throwing glass pieces outward.

(4) Explain why it is advisable to add water to an overheated automobile engine only slowly, and only with the engine running.

Ans. If water is added quickly to an overheated engine, it comes into contact with the very hot metal parts of the engine. Some areas of the metal parts will cool off very rapidly; others will not. Some of the water will quickly turn to steam and will expand rapidly. The net result can be a cracked engine and block the radiator, due to the thermal stress and/or the emission of high-temperature steam from the radiator. Water should always be added slowly, with the engine running. The water will mix with the hotter water already in the system and will circulate through the engine, gradually cooling all parts at about the same rate.

(5) Explain why burns caused by steam at 100°C on the skin are often more severe than burns caused by water at 100°C.

Ans. Steam at 100°C contains more thermal energy than water at 100°C. The difference is due to the latent heat of vaporization (L_v), which for water is quite

high. As the steam touches the skin and condenses, a large amount of energy is released, causing more severe burns. And the condensed water is still at 100°C, so more burning can occur as that water cools.

(6) Explain why cities like Karachi situated by the ocean tend to have less extreme temperatures than inland cities at the same latitude.

Ans. Cities situated on the ocean have less extreme temperatures because the oceans are heat reservoirs. Due to ocean currents, the temperature of the ocean in a locale will be fairly constant during a season. In the winter, the ocean temperature remains above freezing. Thus, if the air and land near the ocean get colder than the oceans, the oceans will release thermal energy, moderating the temperature of the nearby region. Likewise, in the warm seasons, the ocean temperatures will be cooler than the surrounding land mass, which heats up more easily than the water. Then the oceans will absorb thermal energy from the surrounding areas, again moderating the temperature.

(7) An iron rim which is fixed around a wooden wheel is heated before its fixture. Explain why?

Ans. An iron rim is heated before its fixture around a wooden wheel because of the thermal expansion.

Metals expand on heating and contract on cooling. This expansion and contraction of a metal is a reversible change. The metallic rim used is slightly smaller in

diameter than the wheels. On heating the rim expands. And can easily lie on the wheels. When the rim cools, it contracts and presses tightly on to the wheels.

(8) Why is ice at 0°C a better coolant of soft drinks than water at 0°C?

Ans. Ice is more effective in cooling than water at the same temperature because ice can absorb latent heat as well as the heat energy in order to attain room temperature. Water at 0°C can absorb heat energy only to attain the room temperature. Thus, water can absorb less amount of energy from surroundings compared to ice due to which ice will give more cooling effect as compared to water at the same temperature.

(9) Why we feel cool after perspiration (sweat)?

Ans. We feel cool after perspiration because of the latent heat of evaporation of water from our skin. We know that evaporation causes cooling because it takes away heat of the body. As we sweat in summer and then set in front of fan, the water drops quickly start evaporating and we feel cool.

NUMERICAL PROBLEMS

(1) Perform the temperature conversions (a) Temperature difference in the body. The surface temperature of the body is normally about 7°C lower than the internal temperature. Express this temperature difference in kelvins and in Fahrenheit degrees. (b) Blood storage.

Blood stored at 4.0°C lasts safely for about 3 weeks, whereas blood stored at –160° C lasts for 5 years. Express both temperatures on the Fahrenheit and Kelvin scales.

Solution:

Given:

(a) Difference between body's internal temperature
$\Delta T_{1^\circ C} = 7^\circ C$

(b) Temperature $T_{2^\circ C} = 4^\circ C$

(c) Temperature $T_{3^\circ C} = -160^\circ C$

Required: $\Delta T_{1^\circ F} = ?\ and\ \Delta T_{1K} = ?$

$T_{2^\circ F} = ?\ and\ T_{2K} = ?$

$T_{3^\circ F} = ?\ and\ T_{3K} = ?$

(a) For kelvin, the difference will be same as in Celsius i.e. $\Delta T_{1k} = \boxed{7K}$

For Fahrenheit difference

(b) The relation between Celsius and kelvin and Celsius and Fahrenheit is give by

$T_K = T_{^\circ C} + 273, and, T_{^\circ F} = 1.8T_{^\circ C} + 32$

Putting values of both temperatures.

$T_{1K} = 4 + 273 = \boxed{277K}, and, T_{1^\circ F} = 1.8 \times 4 + 32 = \boxed{39.2^\circ F}$

$T_{2K} = -160 + 273 = \boxed{113K}, and$

$T_{2^\circ F} = 1.8 \times (-160) + 32 = \boxed{-256^\circ F}$

(2) Consider a metre-stick composed of platinum (the coefficient of linear expansion for platinum is $\alpha = 8.8 \times 10^{-6}\ K^{-1}$) By what amount does the length of this metre-stick change if the temperature increases by 1.0 K?

Solution:

Given:

Original length of meter stick $L_o = 1$ m

Coefficient of linear expansion for platinum is $\alpha = 8.8 \times 10^{-6}\ K^{-1}$

Temperature difference $\Delta T = 1.0K$

Required: Change in length $\Delta L = ?$

As here the change in length is per unit length (1m) and per degree rise in temperature (1K), so the change in length will be equal to its coefficient of linear expansion. OR we can also find it through the following relation

$$\Delta L = \alpha L_o \Delta T$$

$$\Delta L = 8.8 \times 10^{-6} \times 1 \times 1 = \boxed{8.8 \times 10^{-6} m}$$

(3) A railway line made of iron is 1200 km long and is laid at 25°C. By how much will it contract in winter when the temperature falls to 15°C? By how much will it expand when the temperature rises to 40°C in summer? (the coefficient of linear expansion for iron is $\alpha = 12 \times 10^{-6}\ K^{-1}$)

Solution:

Given:

Original length of railway line L_o = 1200 km

$= 1.2 \times 10^6$m

Change in temperature $\Delta T_1 = 15 - 25$

$= -10^oC = -10K$

Change in temperature $\Delta T_2 = 40 - 25$

$= 15^oC = 15K$

Coefficient of linear expansion for iron is $\alpha = 12\times10^{-6}\ K^{-1}$

Required: Change in length ΔL_1 = ?

Change in length ΔL_2 = ?

The linear expansion is given by

$\Delta L_1 = \alpha L_o \Delta T_1, and, \Delta L_2 = \alpha L_o \Delta T_2$

Putting values

$\Delta L_1 = 12 \times 10^{-6} \times 1.2 \times 10^6 \times (-10) = \boxed{-144m}$

$\Delta L_2 = 12 \times 10^{-6} \times 1.2 \times 10^6 \times 15 = \boxed{216m}$

(4) The volume of a brass ball is $800cm^3$ at 20°C. Find out the new volume of the ball if the temperature is raised to 52°C. The coefficient of volumetric expansion of brass is $57\times10^{-6}\ K^{-1}$.

Solution:

Given.

Original volume of brass V_o =800 cm^3

Temperature difference $\Delta T = 52 - 20 = 32^oC = 32K$

Coefficient of volumetric expansion of brass $\gamma = 57\times10^{-6}\ K^{-1}$

Required: Change in volume $\Delta V = ?$

The volumetric expansion is given by

$$\Delta V = \gamma V_o \Delta T$$

$$\Delta V = 57\times10^{-6}\times800\times32 = \boxed{1.5cm^3}$$

(5) What is the specific heat of a metal substance if 135 kJ of heat is needed to raise 4.1 kg of the metal from 18.0°C to 37.2°C?

Solution:

Given:

Heat supplied $\Delta Q = 135kJ = 135\times10^3 J$

Mass of metal m = 4.1 kg

Temperature difference $\Delta T = 37.2 - 18$

$$= 19.2^oC = 19.2K$$

Required: Specific heat of metal c =?

The specific heat of solids is given by

$$c = \frac{\Delta Q}{m\Delta T}$$

$$c = \frac{135\times10^3}{4.1\times19.2} = \boxed{1715Jkg^{-1}K^{-1}}$$

(6) How much heat is needed to melt 23.50 kg of silver that is initially at 25°C? (Specific Heat of silver is $c = 230$ J kg^{-1} K^{-1}. Latent heat of fusion for silver is $L_f = 8.82\times10^4$ JKg^{-1}).

Solution:

Given:

Mass of silver m = 23.50 kg

Initial temperature $T_1 = 25°C$

Final Temperature $T_2 = 961.8°C$ (melting temperature of silver)

Temperature difference $\Delta T = 961.8 - 18$

$= 936.8°C = 936.8K$

Required: Heat required ΔQ = ?

Latent heat of fusion for silver

$L_f = 8.82 \times 10^4\ Jkg^{-1}$

Specific Heat of silver $c = 230\ J\ kg^{-1}\ K^{-1}$

The latent heat of fusion of is given by the relation

$\Delta Q_1 = mL_f$

$\Delta Q_1 = 23.50 \times 8.82 \times 10^4 = 2.07 \times 10^6 J$

The specific heat is given by

$\Delta Q_2 = cm\Delta T$

$\Delta Q_2 = 230 \times 23.50 \times 936.8 = 5.06 \times 10^6 J$

Total heat required is given by

$\Delta Q = \Delta Q_1 + \Delta Q_2$

$\Delta Q = 2.07 \times 10^6 + 5.06 \times 10^6 = \boxed{7.11 \times 10^6 J}$

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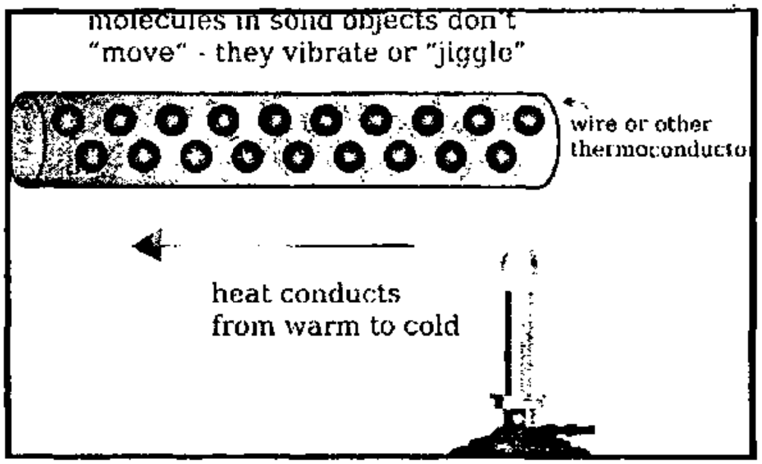
Unit 9

Transfer of Heat

Q.1: Explain conduction of heat and its mechanism. Describe any three of its practical applications.

Ans. Conduction of heat:

Conduction is the flow of thermal energy (heat) through matter from places of higher temperature to places of lower temperature without movement of the matter as a whole.



Explanation:

The handle of a metal spoon held in a hot tea spoon gets warm. Heat passes along the spoon by conduction.

Mechanism of Heat Conduction:

The mechanism of heat conduction can be explained by the behaviour of atoms within the material. The solid iron rod is made of closely packed iron atoms. According to kinetic molecular description of matter the greater the temperature the more is the kinetic energy of atoms or molecules. The atoms in the hotter part of the

rod vibrate more violently (thus possess more kinetic energy) than those in the colder part. Initially, before the rod is inserted into the flame, the iron atoms are vibrating about their equilibrium positions.

As the flame heats the rod, the iron atoms near the flame begin to vibrate with greater speeds and wider distance. These wildly vibrating atoms collide with their neighbouring atoms and transfer some of their energy to these atoms. Which in turn pass thermal energy to their own neighbours and soon. Iron is a metal and contains a large number of electrons that are free to move through the metal called free electrons. These free electrons also play a big part in the conduction of heat. For example, when one end of the iron rod is heated, the atoms in the heated part vibrate more with greater speeds. The free electrons that collide with these atoms gain kinetic energy and move faster. They diffuse into the colder part of the metal where collisions with other free electrons and atoms which result in the transfer of energy.

Examples:

(1) The heat from a hot coffee makes the cup itself hot.

(2) A metal spoon becomes hot from the hot tea inside the cup.

(3) Good heat conductors are used to make electrical appliances such as cooking utensils and iron.

Q.2: Explain thermal conductivity of a substance and its mathematical description.

Ans. *The thermal conductivity of a substance is a measure of the ability of the substance to conduct heat energy.*

Explanation:

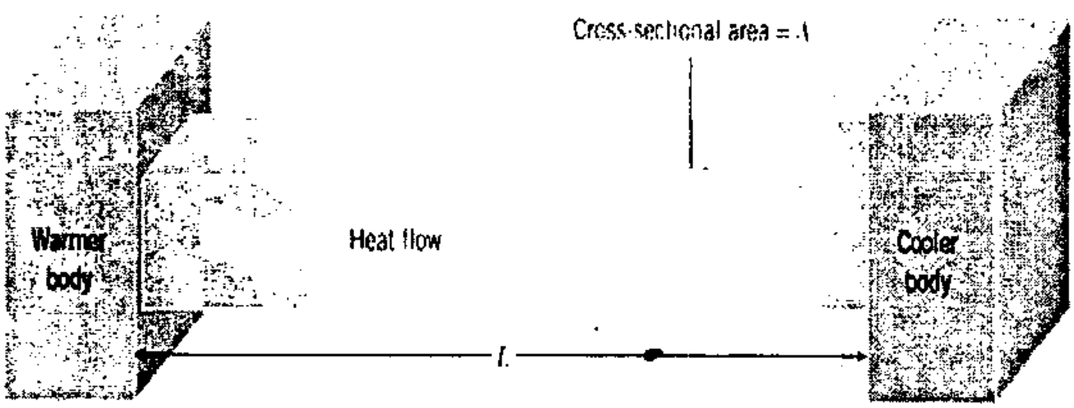
Let us consider a rod of length 'L', area of cross-section 'A'. Let the hot face of the slab be at temperature T_H and the colder face be at temperature T_C, which means $T_H > T_C$. The rate of heat flow (Q/t) across the slab depends on the following factors.

- The difference in temperature ($T_H - T_C$) between the two faces of the slab. Greater the difference, greater the heat flow rate (from hot to cold) will be.
- Greater the length of the slab, smaller the heat flow rate will be. It is because heat has to travel larger path.
- Greater the cross-section area of the slab, greater the heat flow rate will be.

Mathematically,

$$Q/t \propto A \times \frac{T_h - T_c}{L}$$

$$Q/t = k \times A \times \frac{T_h - T_c}{L}$$



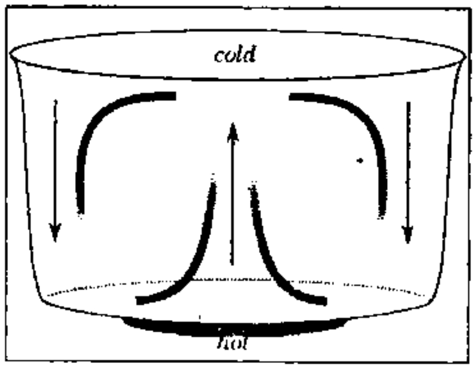
Whereas, k is constant of proportionality and is called as thermal conductivity. It is defined as the quantity of heat which flows through one square metre of

area of the substance in one second when a temperature difference of one kelvin is maintained across a thickness of one meter. The SI unit of thermal conductivity is $W\ m^{-1}\ K^{-1}$ or $J\ m^{-1}\ K^{-1}\ s^{-1}$.

Q.3: Explain convection of heat and its mechanism. Explain any three of its practical applications.

Ans. **Convection of heat:**

The transfer of heat from one place to another by the bulk motion of fluids is called convection.



Explanation:

Convection occurs only in fluids (liquids and gases). Convection cannot occur in solids as the atoms in a solid are located in fixed positions and cannot change place. For the same reason convection occur very easily in gases. Consider a pot full of water, is placed on a burner. As the bottom molecules of water heat up, they go upward while cold molecules move downward because of the convection as shown in the figure.

Mechanism of heat convection:

The heated portion of water at the bottom of expands and becomes less dense. Being less dense, the warm water moves upward. It is replaced by the cold and dense water around it. The cold water flowing to the point of heating in its turn absorbs heat energy, expands

and is pushed upward. Thus, a continuous circulatory flow is established from the bottom to the top of the water. Black marks often appear on the wall or ceiling above a lamp. They are caused by dust being carried upwards in air convection currents produced by the hot lamp or radiator.

Examples:

(1) In refrigerator, the freezer compartment is kept at the top because due to convection cold air moves down to other parts of refrigerator and hot air upwards.

(2) In geyser, the exit pipe is taken from the top because due to conviction hot water moves upward and cold water downward.

(3) In rooms, exhaust fans are installed near the ceiling because hot air moves upward and is taken out by the exhaust fan.

Q.4: Explain radiation of heat and its mechanism. Describe any three of its practical applications.

Ans. Radiation of heat:

The heat transfer from a hotter place to a colder place with or without having a material medium in between is called radiation of heat.

Explanation:

When we sit next to an open campfire, the heat from the fire does not reach us by conduction because air is a bad conductor of heat. It does not reach us by convection because hot air rises up. In this case, the heat reaches us by radiation of heat. The hot fire radiates heat rays just as light rays. When these rays fall on anything they make that object hotter.

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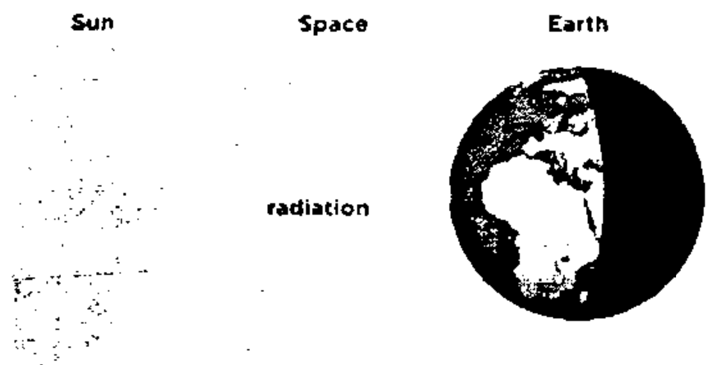
Mechanism of heat radiation:

The mechanism of radiation is energy transfer by electromagnetic waves. Electromagnetic radiation comes from accelerating electric charges. On molecular level, that's what happens as objects warm up, their molecules vibrate harder and harder, causing acceleration of electric charges which emits those radiations. Heat energy transferred through radiation is as familiar as the light; in fact, it is the light but not visible or barely visible. Electromagnetic waves (radiation) can transfer energy via vacuum or empty space as well as via a material medium like glass. Every object around us is continually radiating, unless its temperature is at absolute zero 0 K, which is not possible.



Examples:

(1) The heat from sun reaches us passing through vacuum due to radiation of heat as shown in the figure.

(2) We feel hot while setting near the fire. As air is bad conductor of heat, yet we receive it due to radiation of heat.

(3) Turned on heater in a room in winter warms the room because of the radiation.

Q.5: Discuss the greenhouse effect. Explain its importance and global warming concern.

Ans. Greenhouse effect:

The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere.

Explanation:

The strength of the greenhouse effect will depend on the atmosphere's temperature and on the amount of greenhouse gases that the atmosphere contains.

Mechanism of greenhouse effect:

Earth receives energy from the Sun in the form of ultraviolet, visible, and near-infrared radiation. Of the total amount of solar energy available at the top of the atmosphere, about 26% is reflected to space by the atmosphere and clouds and 19% is absorbed by the atmosphere and clouds. Most of the remaining energy is absorbed at the surface of Earth. Because the Earth's surface is colder than the photosphere of the Sun, it radiates at wavelengths that are much longer than the wavelengths that were absorbed. Most of this thermal radiation is absorbed by the atmosphere, thereby warming it. In addition to the absorption of solar and thermal radiation, the atmosphere gains heat by latent heat fluxes from the surface.

Importance of greenhouse effect:

Greenhouse effect is important for the survival of life on earth. On Earth, an atmosphere containing naturally occurring amounts of greenhouse gases (water vapour, carbon dioxide CO_2, methane CH_4, and ozone O_3) cause air temperature near the surface to be about 33 °C (59 °F) warmer than it would be in their absence. Without

the Earth's atmosphere, the Earth's average temperature would be well below the freezing temperature of water.

Global warming:

The increase in average temperature of earth is called global warming.

Human activity has increased the amount of greenhouse gases in the atmosphere leading to global warming (increase in the temperature of earth) Due to human activities in the period from 1880 to 2012; the global average temperature has increased by 0.85°C. Currently, about half of the carbon dioxide released from the burning of fossil fuels is not absorbed by vegetation and the oceans and remains in the atmosphere. Now in order to decrease global warming we have to reduce the emission of greenhouse gases and to plant more vegetation to absorb the produced carbon dioxide.

Examples and Assignments:

EXAMPLE 9.1:

STYROFOAM ICE BOX

A Styrofoam (k = 0.010 W/mK) ice box has a total area of 0.950m^2 and walls with an average thickness of 2.50cm. The box contains ice, water, and canned beverages at 0°C. The inside of the box is kept cold by melting ice. What is the rate of energy transfer in J/s if the ice box is kept at 35.0°C?

Solution:

Given:

Area A = 0.950 m^2

Length L = 2.50 cm = 0.025 m

Temperature difference $\Delta T = T_h - T_c = 35 - 0$

$= 35°C = 35K$

Thermal conductivity of Styrofoam
$k = 0.010 Wm^{-1}k^{-1}$

Required: Rate of heat transfer $Q/t = ?$

The rate of heat (energy) is given by

$$Q/t = k \times A \times \frac{T_h - T_c}{L}$$

$$Q/t = 0.010 \times 0.950 \times \frac{35}{0.025}$$

$$Q/t = \boxed{13.3Js^{-1}} = \boxed{13.3w}$$

ASSIGNMENT 9.1:

<u>CONCRETE WALL 0.20M THICK</u>

Find the amount of heat transferred in one hour through a concrete wall of area 6.9m^2, and 0.20m thick. One side of the wall is held at 20°C and the other side is at 5°C. The thermal conductivity of concrete is 1.3JK^{-1}m^{-1}s^{-1}.

<u>Solution:</u>

Given:

Area A = 6.9 m^2

Length L = 0.20 m

Time t = 1 hour = 3600 s

Temperature difference $\Delta T = T_h - T_c = 20 - 5$

$= 15°C = 15K$

Thermal conductivity of Styrofoam
$k = 1.3\ J\ K^{-1}m^{-1}s^{-1}$

Required: Heat transfer Q = ?

The heat (energy) is given by

$$Q = k \times A \times \frac{T_h - T_c}{L} \times t$$

$$Q = 1.3 \times 6.9 \times \frac{15}{0.20} \times 3600$$

$$Q = \boxed{2.4 \times 10^6\ J}$$

EXERCISE

Multiple Choice Questions:

(1) Which of the following is the best heat conductor?

A. aluminium B. Tin

C. Iron D. copper

(2) Identical cubes of the following materials are kept in a room at the same temperature. Which will feel coldest by touching them?

A. Wood B. Glass

C. Iron D. Styrofoam

(3) The transfer of heat by convection is smallest in

A. solids B. Liquids

C. Gases D. none

(4) One way that heat is transferred from place to place inside the human body is by the flow of blood. Which one of the following heat transfer processes best describes this action of the blood?

A. convection B. Conduction

C. Radiation D. none

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(5) The best absorber of radiation is a body whose surface is

A. White B. Grey

C. Dull black D. Highly polished

(6) The mode of transfer of heat which does not require material medium is called

A. Convection B. Conduction

C. Radiation D. none

(7) Which of the following has the highest thermal conductivity?

A. Water B. Wood

C. Wool D. air

(8) The temperature at which a body is not radiating any heat is

A. 0°C B. 0°F

C. 0 K D. all of these

(9) The electrons that are free to move through the metal called

A. lose electrons B. free electrons

C. conduction electrons D. holes

ANSWERS:

1.D	2.C	3.A	4.A	5.C	6.C	7.A	8.C	9.B	

CONCEPTUAL QUESTIONS

(1) Why white clothes are preferred to wear in summer? Explain briefly.

Ans. White clothes are preferred to wear in summer because it emits all the radiations falling upon it and do not absorb any of it.

Explanation:

The light rays from sun fall on your clothes. If you wear white clothes then no single radiation (composed of heat) is absorbed by your clothes. It is because white colour does not absorb radiations and you will feel comparatively cool than wearing any other colour of clothes. We should avoid wearing black or other dark colour clothes in summer.

(2) Why is the freezer compartment kept at the top of a refrigerator? Explain briefly.

Ans. Freezer is the source for the refrigerator's coldness. When the freezer is placed on top, the cold air produced from it is denser than the warmer air in the bottom, so cold air being dense sinks down and the warm air is forced to rise up. When the warm air rises up it gets cold in the freezer, which is the principle for the uniform cooling of a single compartment refrigerator. In general, top-mounted freezers offer greater energy efficiency than any other type of refrigerator design.

(3) A black car, standing in the sun, warms up more quickly than any other. Why?

Ans. A black car standing in the sun warms more quickly than any other because black colour is a good absorber of radiations and can absorb almost all colour of radiations.

As black colour is a good absorber of radiations and can absorb a wide range of wavelengths that is why a black body absorbs more heat than any other colour when exposed to sun.

(4) Why a tile floor feels colder to bare feet than a carpeted floor?

Ans. The tile feels colder because it is a good heat conductor and it moves heat rapidly away from your skin that is warmer than air temperature. The carpet would be a heat insulator. The carpet slows down the flow of the heat which would make it feel warm. But if both the tile floor and carpeted floor are exposed to sun, then carpeted floor will feel colder then tile floor.

(5) How woolen sweaters keep us warmer in winter?

Ans. Woolen clothes keep us warm during winter because wool is a poor conductor of heat and it has air trapped in between the fibres. In contrast Cotton clothes are thin and do not have space in which air can be trapped. Thus, cotton clothes do not prevent heat coming out of our body.

(6) In certain places, birds can fly for hours without flapping their wings. Explain.

Ans. In warm places, air gets heated and rises which are called thermals or convection current. Due to these thermals birds are able to fly for hours without flapping their wings.

(7) Good-quality thermos bottle is double-walled and evacuated between these walls, and the internal surfaces are like mirrors with a silver coating. How does this configuration combat heat loss from all three transfer methods and keep the bottle's contents—your coffee—hot?

Ans. Due to the evacuation between two walls of the thermos, there is no chance for heat to transfer through conduction or convection. As for it we need a medium which is not there. The internal surfaces are like mirrors which cause the radiation to reflect again and again, decreasing the chances of heat loss through radiation. That is why your coffee will remain hot for a long time in thermos.

(8) A piece of wood lying in the Sun absorbs more heat than a piece of shiny metal. Yet the metal feels hotter than the wood when you pick it up. Explain.

Ans. It is due to high conductivity of metal that it feels hotter than the wood when placed/kept in sun for a while. In contrast if we put the same metal and wood in a room then the metal will be colder than the wood.

(9) Some pot handles remain cool during cooking while others become unpleasantly hot. What determines which handles remain cool and which become hot?

Ans. Those pot handles which are made up of insulators (like wood or plastic) remain cool during cooking

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and others that are made up of conductors (like steel) become unpleasantly hot.

(10) When sunlight warms the land beside a cool body of water, a breeze begins to blow from the water toward the land. Explain.

Ans. It is because of the convection of heat. As the land warms, hot air moves upward which decreases air pressure just above the land. Cool air from water surface rushes towards the land because of pressure difference called sea breeze. That is why we feel cool breeze near sea.

NUMERICAL PROBLEMS

(1) A person's body is covered with $1.6m^2$ of wool clothing. The thickness of the wool is 2.0×10^{-3}m. The temperature at the outside surface of the wool is 11°C, and the skin temperature is 36°C. How much heat per second does the person lose due to conduction? Thermal conductivity of wool is $k=0.04Wm^{-1}K^{-1}$.

Solution:

Given:

Area A = 1.6 m^2

Thickness $T = 2.0 \times 10^{-3} m$

Temperature difference $\Delta T = T_h - T_c = 36 - 11$

$= 25°C = 25K$

Thermal conductivity of Wool $k = 0.04Wm^{-1}k^{-1}$

Required: Rate of heat transfer $Q/t = ?$

The rate of heat (energy) is given by

$$Q/t = k \times A \times \frac{T_h - T_c}{T}$$

$$Q/t = 0.04 \times 1.6 \times \frac{25}{2.0 \times 10^{-3}}$$

$$Q/t = \boxed{800W}$$

(2) The external wall of a brick house has an area of 16m² and thickness 0.3m. The temperatures inside and outside the house are respectively 20°C and 0°C. Calculate the rate of heat loss through the wall. Thermal conductivity of brick is k = 0.84 W m⁻¹ K⁻¹.

Solution:

Given:

Area A = 16 m^2

Thickness T = 0.3m

Temperature difference $\Delta T = T_h - T_c = 20 - 0$

$= 20°C = 20K$

Thermal conductivity of Wool $k = 0.84Wm^{-1}k^{-1}$

Required: Rate of heat transfer $Q/t = ?$

The rate of heat (energy) is given by

$$Q/t = k \times A \times \frac{T_h - T_c}{T}$$

$$Q/t = 0.84 \times 16 \times \frac{20}{0.3}$$

$$Q/t = \boxed{896W}$$

(3) Window glass has thermal conductivity of 0.8 $Wm^{-1}K^{-1}$. Calculate the rate at which heat is conducted through a window of area 2.0m^2 and thickness 4.0mm. The temperature inside an air-conditioned room is 20°C. The outdoors temperature is 35°C.

Solution:

Given:

Area A = 2.0 m^2

Thickness $T = 4mm = 0.004m$

Temperature difference $\Delta T = T_h - T_c = 35 - 20$

$= 15°C = 15K$

Thermal conductivity of window glass
$k = 0.8Wm^{-1}k^{-1}$

Required: Rate of heat transfer Q/t = ?

The rate of heat (energy) is given by

$$Q/t = k \times A \times \frac{T_h - T_c}{T}$$

$$Q/t = 0.8 \times 2.0 \times \frac{15}{0.004}$$

$$Q/t = \boxed{6,000W = 6kW}$$

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PR IX (01) 18

PHYSICS

(Fresh/Reappear)

Time Allowed: 3 Hours Marks: 65

1: ہر سوال کے سامنے چار دائرے دیے گئے ہیں، صرف صحیح جواب والا دائرہ بھر دیں۔
2: دائروں کو شیڈ (بھرنے) کے لئے کالےیا نیلے رنگ کا پین استعمال کریں۔
3: جواب میں ایک سے زائد دائرے بھرنے سے جواب غلط تصور ہوگا۔

Time Allowed: 15 minutes Marks: 12

Section - A

1. One Newton per one square meter is equal to__________.
   - ○ 1 joule ○ 1 watt
   - ● 1 Pascal ○ 1 N
2. The temperature of a normal human body is__________.
   - ● 37°C ○ 0°K
   - ○ 32°F ○ 89°F
3. Thermal conductivity of silver is__________ $W.K^{-1}.m^{-1}$.
   - ● 430 ○ 400
   - ○ 240 ○ None of these
4. Dark rough surfaces are generally good for__________.
   - ○ Reflection ● Radiation
   - ○ Conduction ○ Convection
5. Anticlockwise torque is taken__________
   - ○ Zero ● Positive
   - ○ Negative ○ Parallel

6. The value of "g" at moon surface is__________

○ 8.9 m/sec^2 ○ 1.63 m/sec

○ 9.8 m/sec^2 ● 1.63 m/sec^2

7. When a candle bums then chemical energy is transferred to__________ energy.

○ Heat ○ Electrical

○ Light ● A and C both

8. Work done will be zero when the angle between force and displacement is __________.

○ 30° ○ 45°

○ 60° ● 90°

9. The diameter of an atomic nucleus is about__________.

○ 1×10^{-14} m ● 1×10^{-15} m

○ 1×10^{-16} m ○ 1×10^{-18} m

10. The prefix PICO means a factor of__________.

○ 10^{-6} ○ 10^{-9}

● 10^{-12} ○ 10^{-15}

11. The study of motion of bodies under the action of a force is called__________.

● Mechanics ○ Kinematics

○ Geophysics ○ Dynamics

12. $1kg \times 1m/sec^2 =$ __________

○ 1 watt ○ 1 joule

● 1 Newton ○ 1 Pascal